Materials Science

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Textbooks:

Callister W.D. Materials Science and Engineering, An Introduction, John Wiley & sons (e-book posted in LMS)

Jones D.R.H., Michael F.A. Engineering Materials 1; An Introduction to properties, Applications and design, Butterworth - Heinemann Publishers

What is materials science?
Why should we know about it?

A Brief Introduction to Materials Science and Engineering

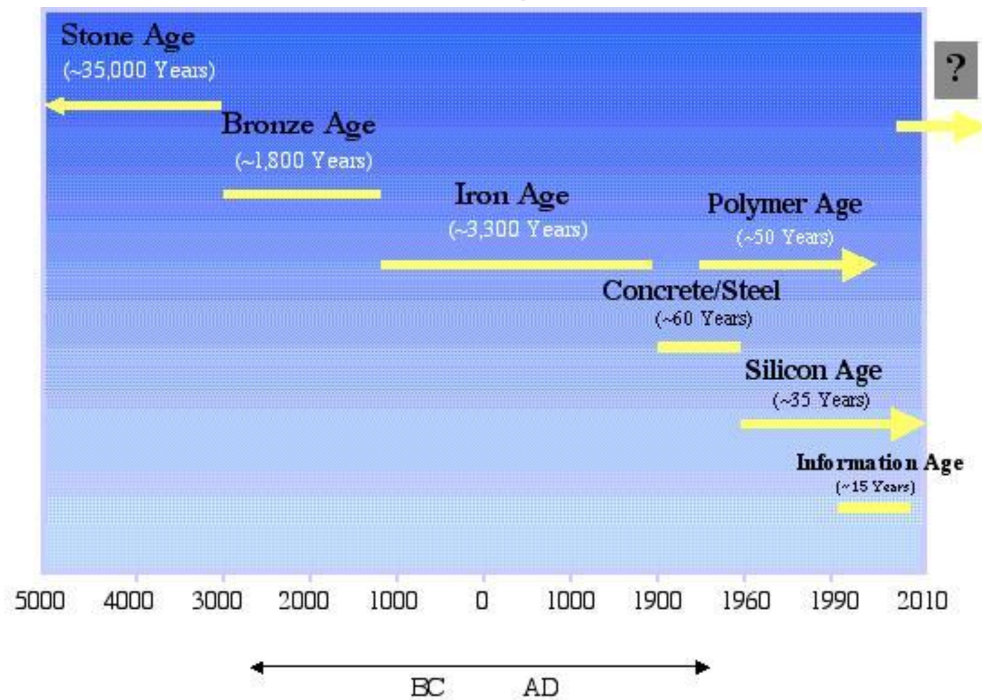
Why the Study of Materials is Important?

- Production and processing of materials constitute a large part of our economy.
- Engineers choose materials to suite design.
- New materials might be needed for some new applications.
- Modification of properties might be needed for some applications.

Foundations of Mat. Sci. and Eng. W.Smith, J. Hashemi, McGraw Hill
http://highered.mcgraw-hill.com/

History of Materials Science & Engineering

- materials closely connected our culture
- the development and advancement of societies are dependent on the available materials and their use
- early civilizations designated by level of materials development



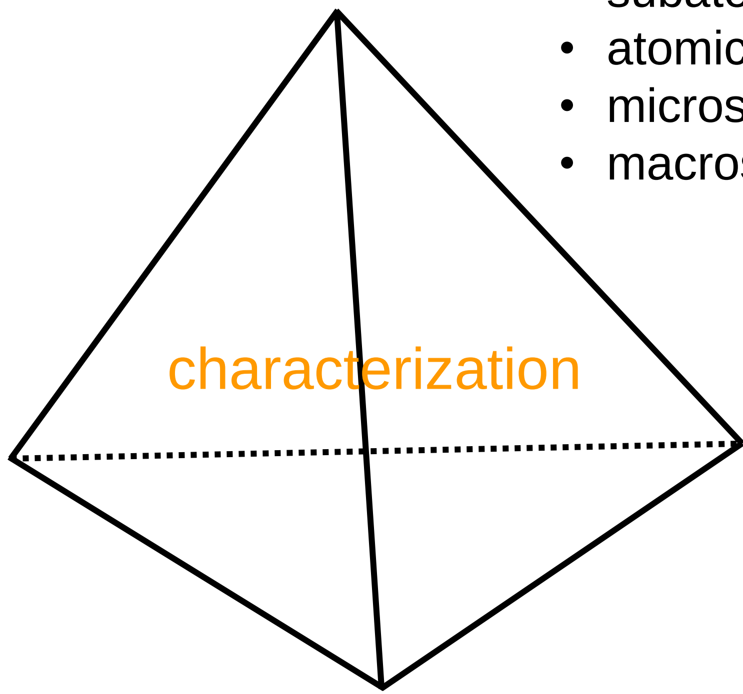
- initially natural materials
- develop techniques to produce materials with superior qualities (heat treatments and addition of other substances)

MATERIALS SELECTION!

Materials Science and Engineering

structure

- arrangement of internal components
- subatomic
- atomic
- microscopic
- macroscopic (bulk)



processing

- method of preparing material

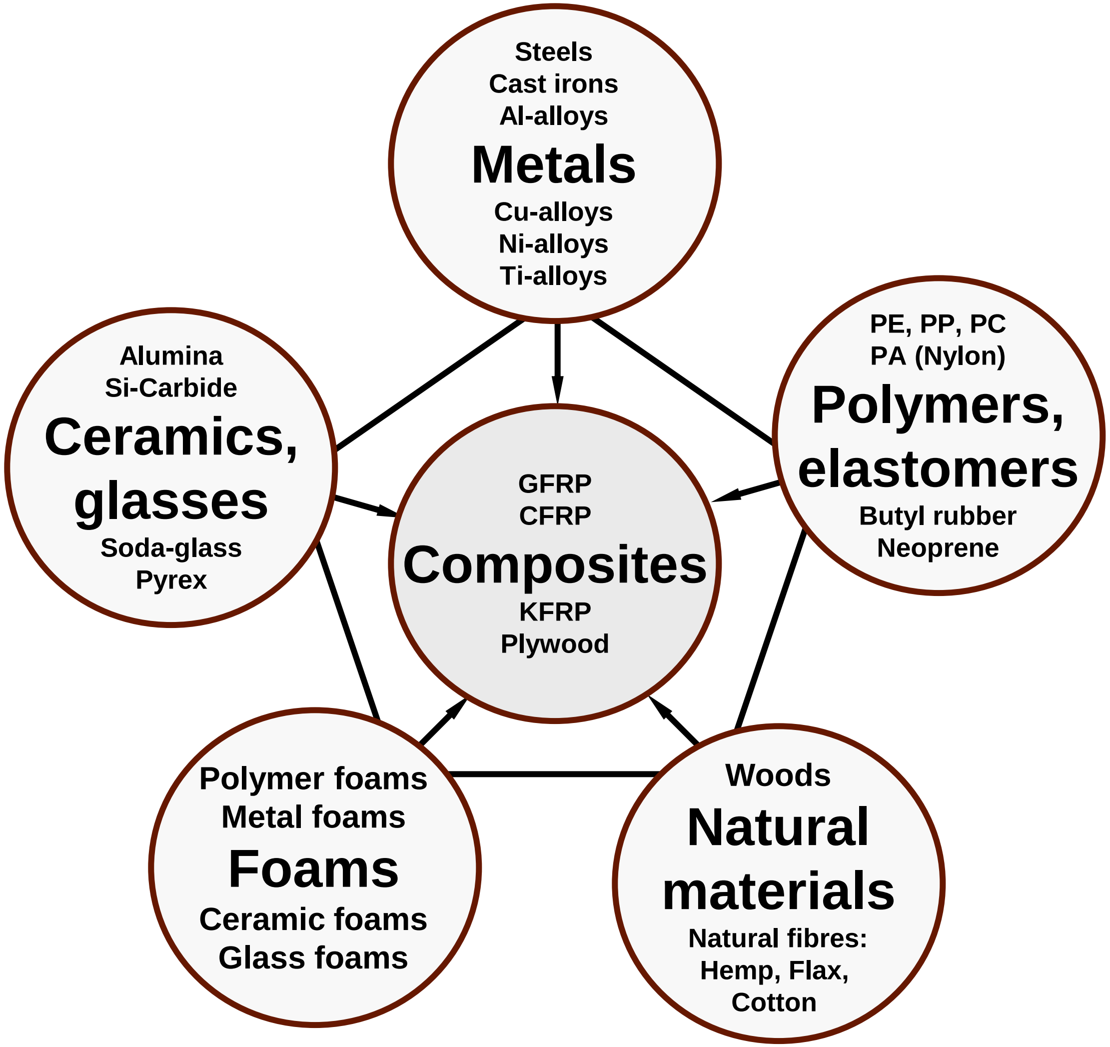
properties

- material characteristic
- response to external stimulus
- mechanical, electrical, thermal, magnetic, optical, deteriorative

performance

- behavior in a particular application

The world of materials – Year 2000



Classification of Materials

Metals

- good conductors of electricity and heat
- lustrous appearance
- susceptible to corrosion
- strong, but deformable

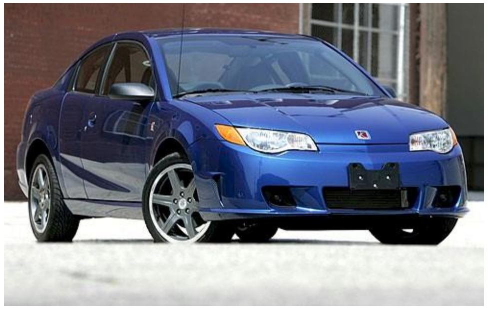


Ceramics & Glasses

- thermally and electrically insulating
- resistant to high temperatures and harsh environments
- hard, but brittle


Polymers

- very large molecules
- low density, low weight
- maybe extremely flexible



Classification of Materials: A Few Additional Catagories

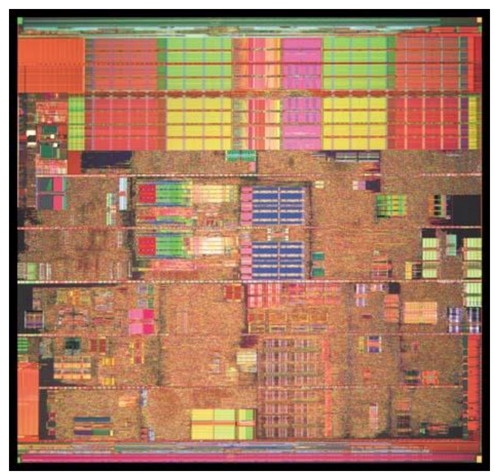
Biomaterials

- implanted in human body
- compatible with body tissues

hip replacement

Semiconductors

- electrical properties between conductors and insulators
- electrical properties can be precisely controlled



Intel Pentium 4

Composites

- consist of more than one material type
- designed to display a combination of properties of each component

fiberglass surfboards

Why study materials?

- applied scientists or engineers must make material choices
- materials selection
  - in-service performance
  - deterioration
  - economics

BUT…really, everyone makes material choices!

aluminum

glass

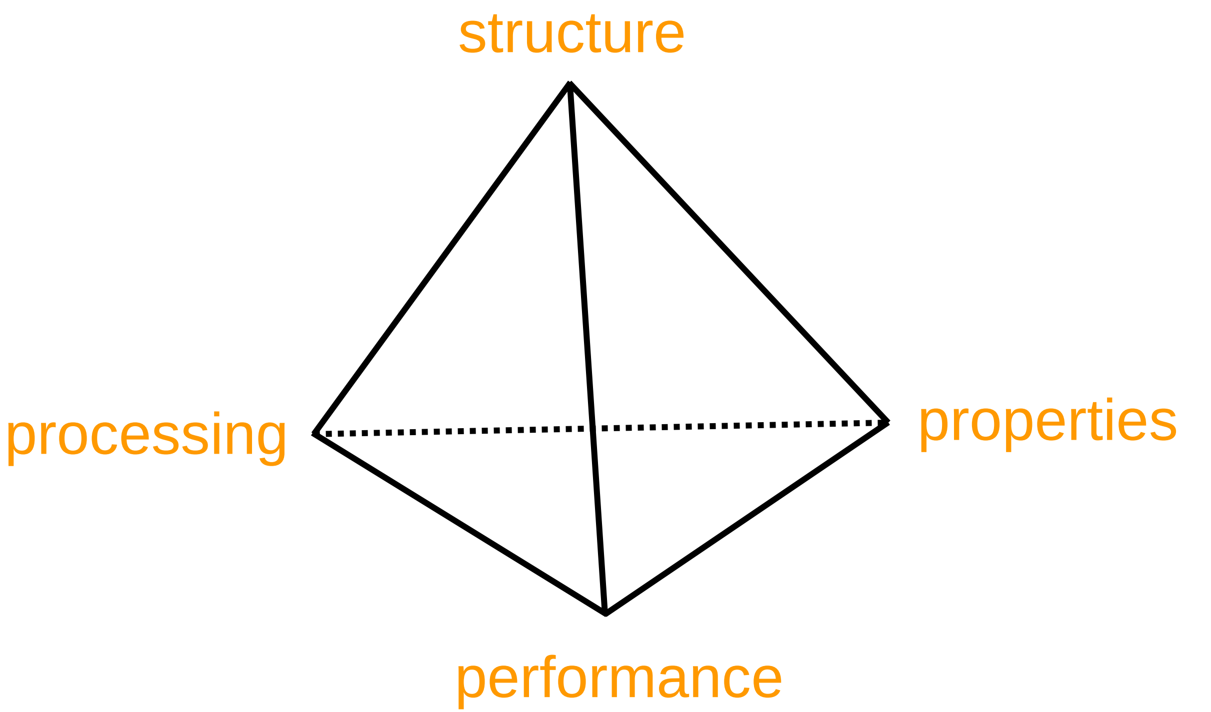
plastic

Types of Materials

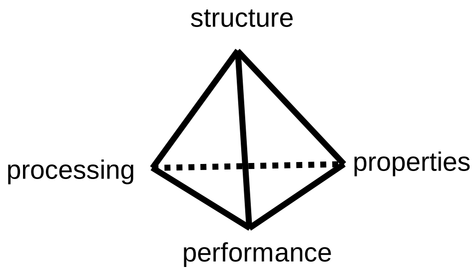
- **Metals**:
  - Strong, ductile
  - High thermal & electrical conductivity
  - Opaque, reflective.

- **Polymers/plastics**: Covalent bonding → sharing of e's
  - Soft, ductile, low strength, low density
  - Thermal & electrical insulators
  - Optically translucent or transparent.

- **Ceramics**: ionic bonding (refractory) – compounds of metallic & non-metallic elements (oxides, carbides, nitrides, sulfides)
  - Brittle, glassy, elastic
  - Non-conducting (insulators)


structure
processing
properties
performance

Levels of Structure



Sub-atomic, atomic, microscopic, bulk

STRUCTURE (length scale)

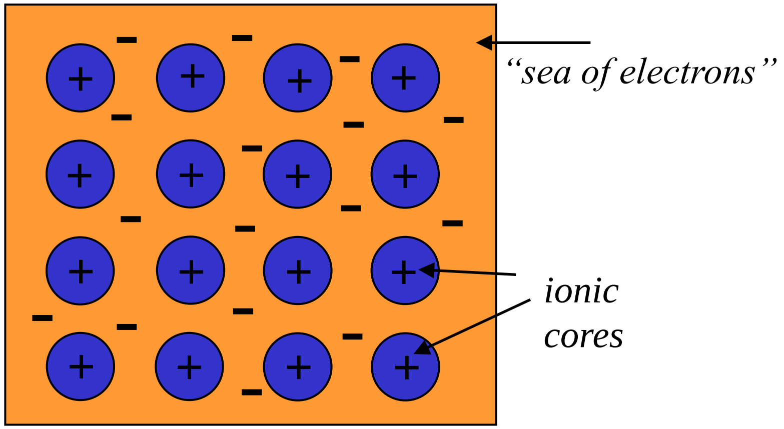
Sub-atomic

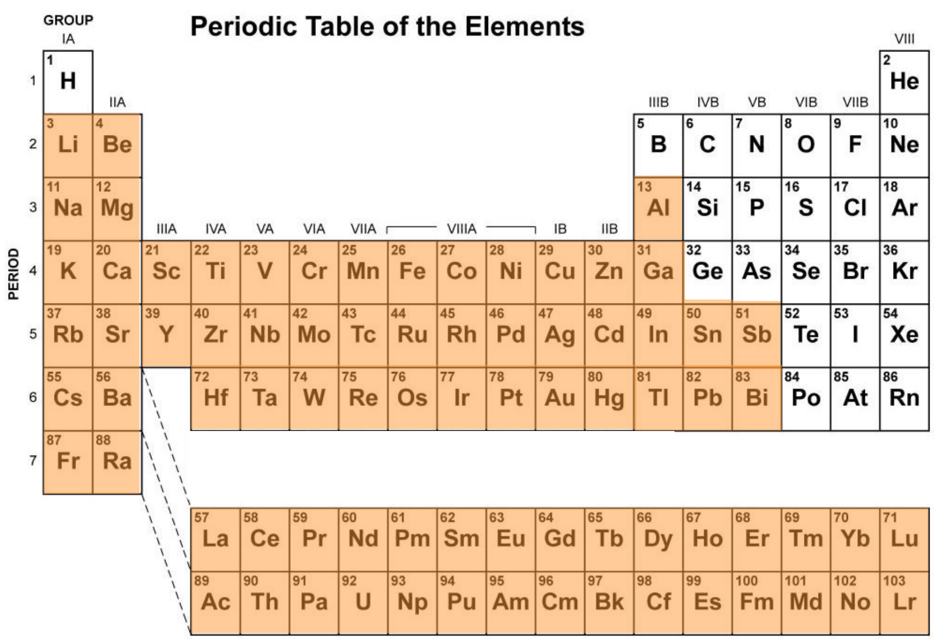
< 0.2 nm

Metals

Metallic Bond

- one, two, or three valence electrons
- valence electrons free to drift through the entire material forming a *"sea of electrons"* surrounding net positive *ionic cores*
- non-directional bond



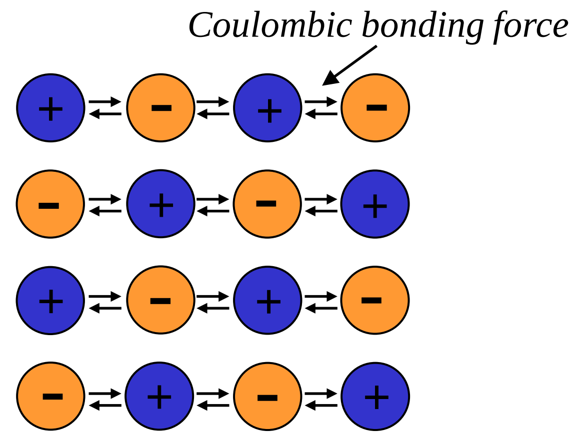


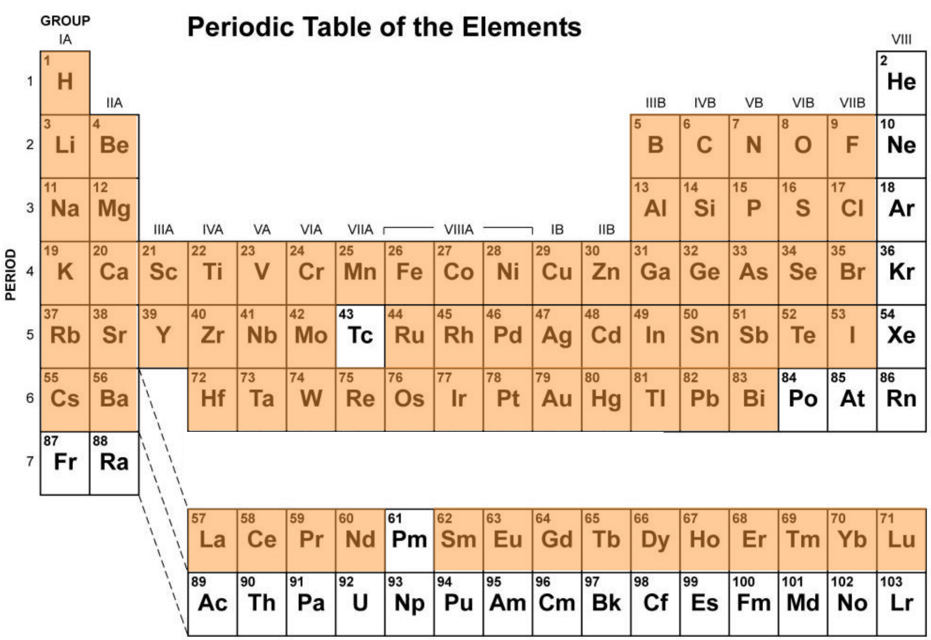
Properties

- good conductors of electricity and heat
- lustrous appearance
- susceptible to corrosion
- strong, but deformable

Ceramics and Glasses

Ionic Bond
- composed of metallic and non-metallic elements
- metallic elements give up valence electrons to non-metallic elements
- all atoms have filled “inert gas” configuration
- ionic solid
- non-directional bond



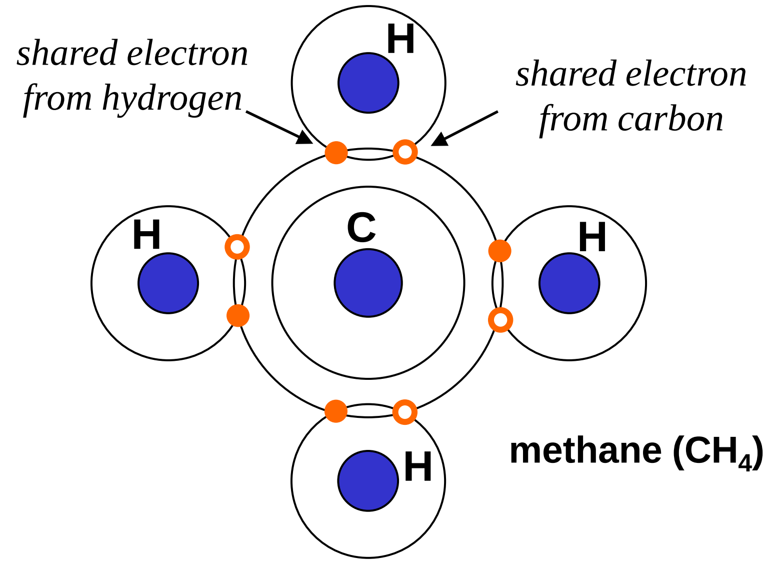


Ceramics & Glasses
- thermally and electrically insulating
- resistant to high temperatures and harsh environments
- hard, but brittle

Polymers

Covalent Bond

- electrons are shared between adjacent atoms, each contributing at least one electron
- shared electrons belong to both atoms
- directional bond



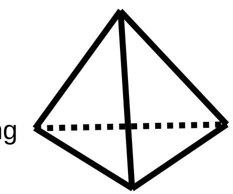
Periodic Table of the Elements

PERIOD	GROUP IA	IIA	IIIA	IVA	VA	VIA	VIIA	VIIIA	VIIIA	VIIIA	IB	IIB	IIIB	IVB	VB	VIB	VIIB	VIII
1	1 H																	2 He
2	3 Li	4 Be											5 B	6 C	7 N	8 O	9 F	10 Ne
3	11 Na	12 Mg											13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
4	19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
5	37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
6	55 Cs	56 Ba		72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn
7	87 Fr	88 Ra																
				57 La	58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb	71 Lu
				89 Ac	90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No	103 Lr

Polymers

- very large molecules
- low density, light weight materials
- maybe extremely flexible

Levels of Structure



STRUCTURE (length scale)

Sub-atomic

< 0.2 nm
1 nm = ?

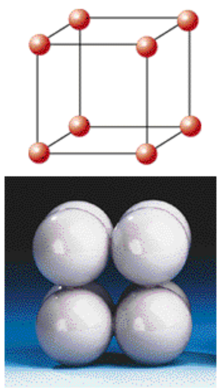
Atomic

0.2-10 nm

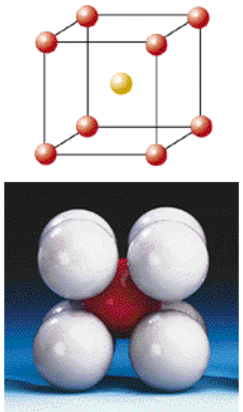
Atomic Arrangement: Ordered vs. Disordered

Crystalline:

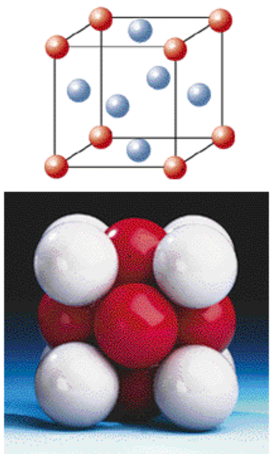
atoms are arranged in a 3D, periodic array giving the material "*long range order*"



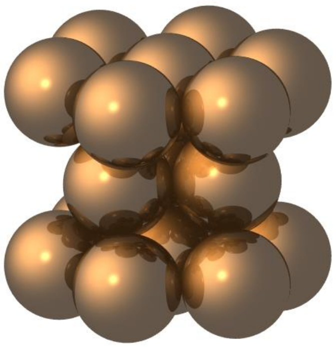
simple cubic



body-centered cubic



face-centered cubic

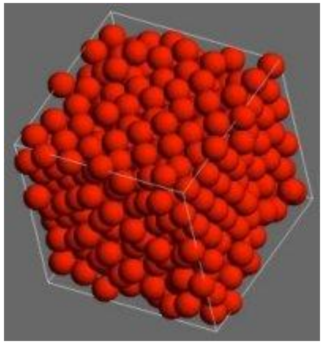


hexagonal close-packed

- stacking can effect properties (i.e. ductility)
- anisotropic materials

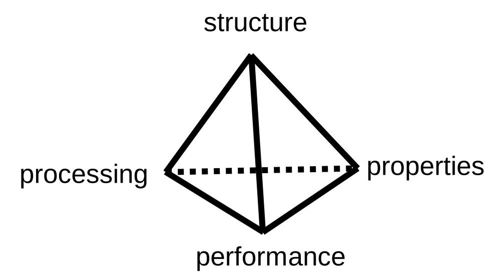
Non-crystalline or amorphous:

atoms only have short-range, *nearest neighbor order*



- viscous materials (generally complex formulas) or rapid cooling
- isotropic materials

Levels of Structure



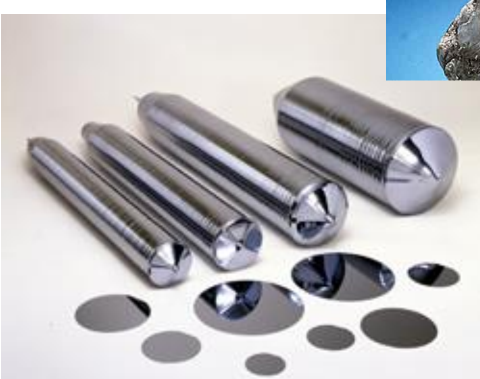
STRUCTURE (length scale)

Sub-atomic	Atomic	Microscopic
< 0.2 nm 1 nm = ?	0.2-10 nm	1-1000 μm

Microstructure

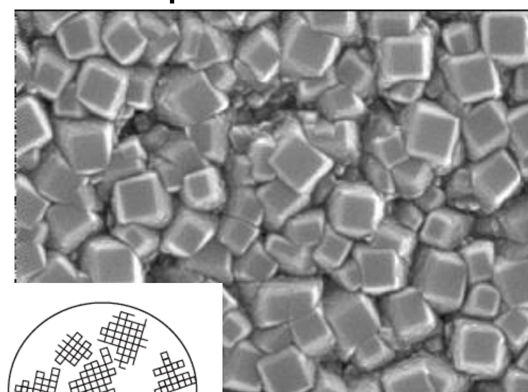
Single Crystal

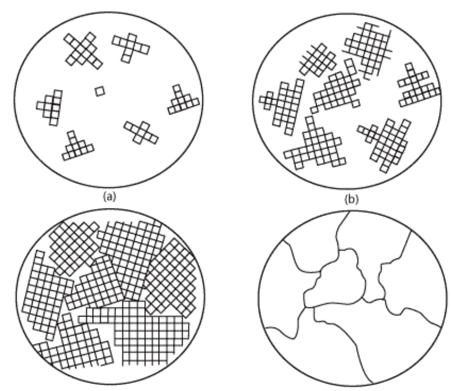
- the periodic arrangement of atoms extends throughout the entire sample
- difficult to grow, environment must be tightly controlled
- anisotropic materials



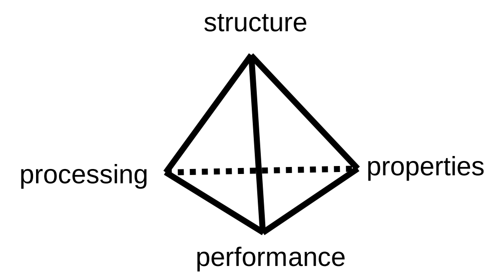
Polycrystalline

- many small crystals or grains
- small crystals misoriented with respect to on another
- several crystals are initiated and grow towards each other
- anisotropic or isotropic materials





Levels of Structure

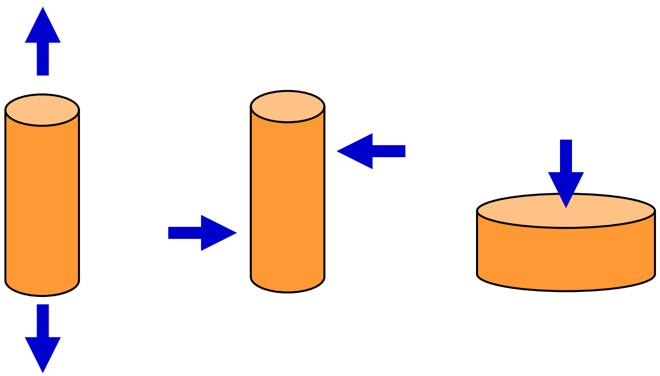


STRUCTURE (length scale)

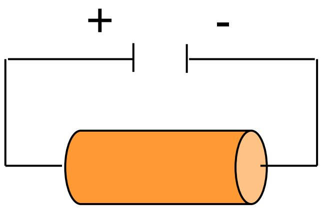
Sub-atomic	Atomic	Microscopic	Bulk
< 0.2 nm 1 nm = ?	0.2-10 nm	1-1000 μm	> 1 mm

Bulk Properties

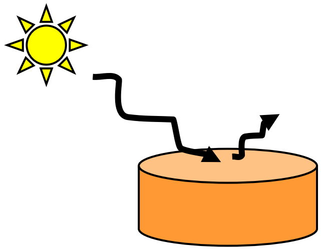
Mechanical:
elastic modulus
shear modulus
hardness



Electrical:
conductivity
resistivity
capacitance



Optical:
reflectivity
absorbance
emission

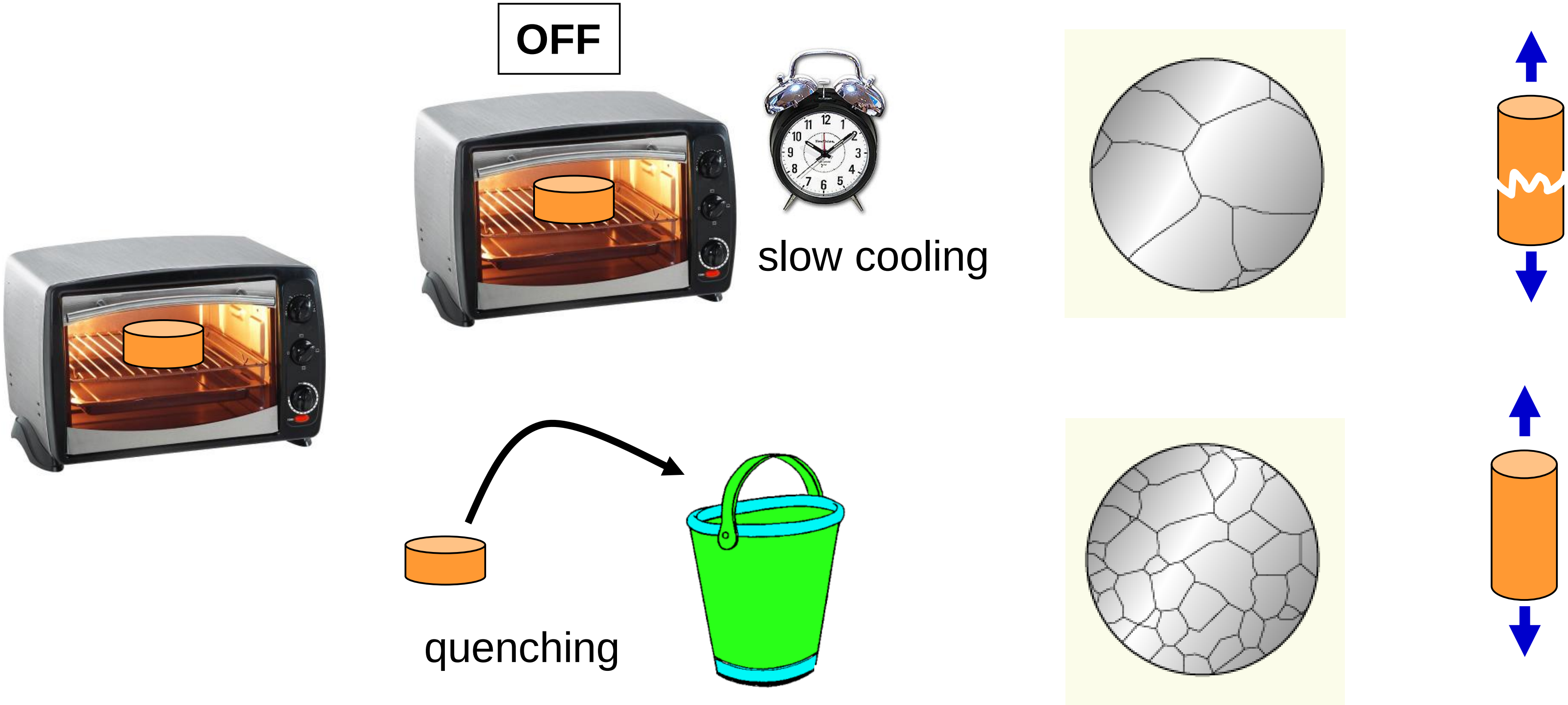


Thermal:
thermal expansion
heat capacity
thermal conductivity

Processing → Structure → Properties → Performance

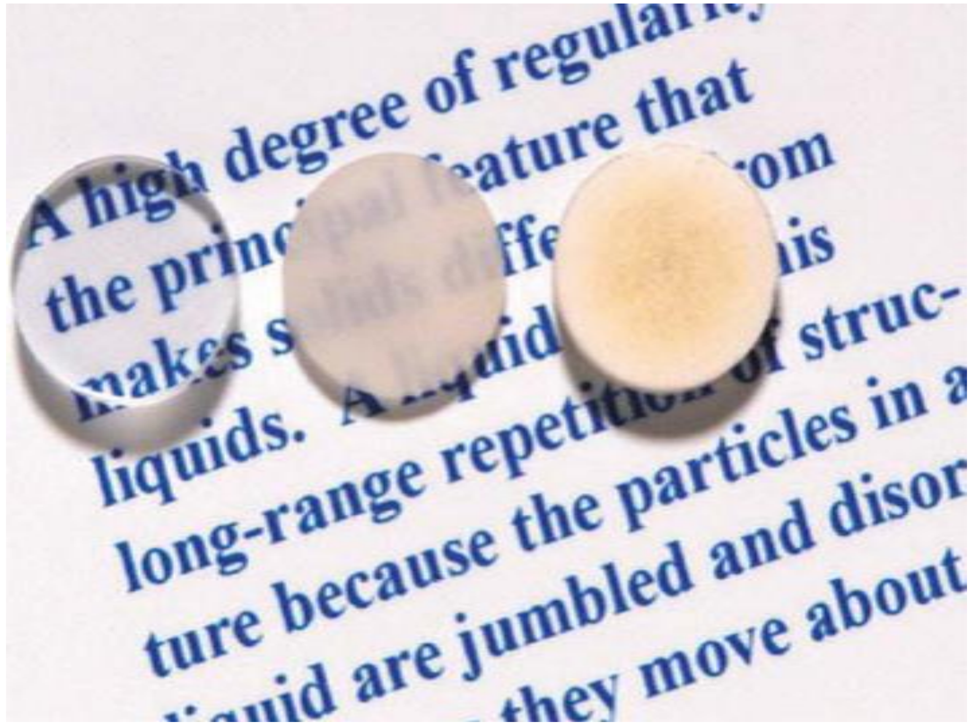
<u>Performance Goal:</u> increased strength from a metallic material

In actuality, crystals are NOT perfect. There are **defects**!
In metals, **strength** is determined by how easily defects can move!



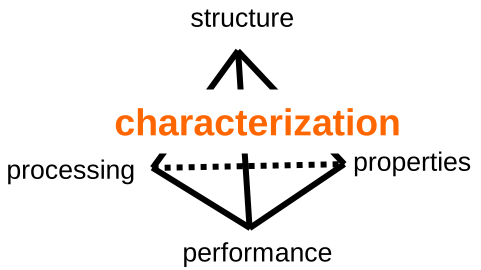
Processing →Structure →Properties →Performance

Aluminum Oxide (Al_2O_3)



single-crystal (transparent)	polycrystalline, fully dense (translucent)	polycrystalline, 5% porosity (opaque)

Characterization Techniques

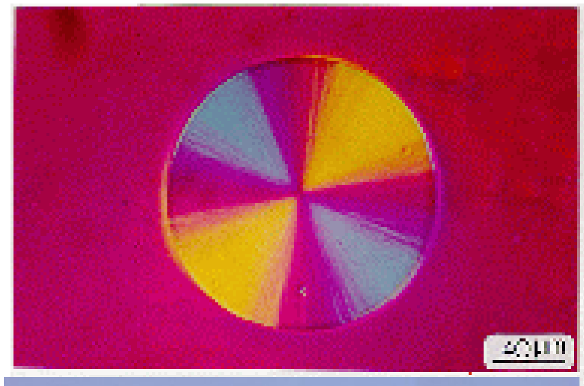


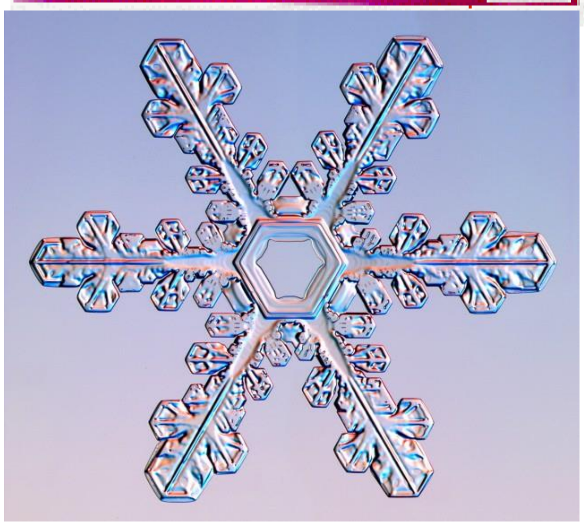
STRUCTURE (length scale)

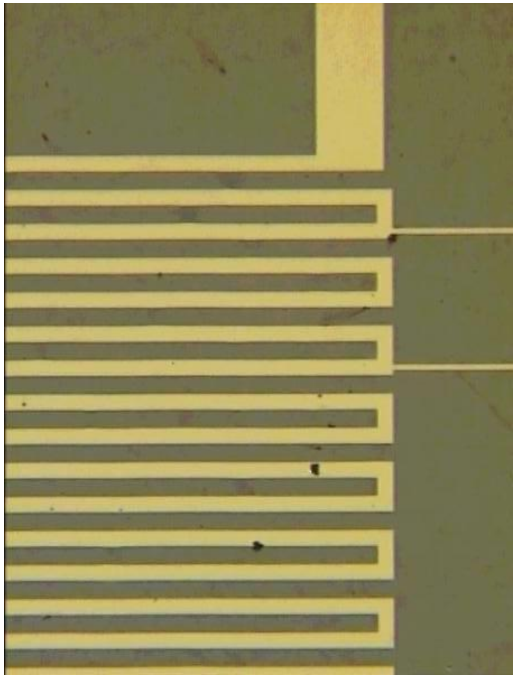
Sub-atomic	Atomic	Microscopic	Bulk
< 0.2 nm 1 nm = ?	0.2-10 nm	1-1000 μm	> 1 mm

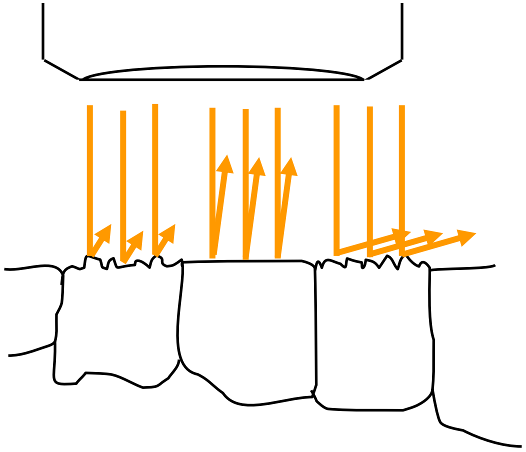
Optical Microscopy

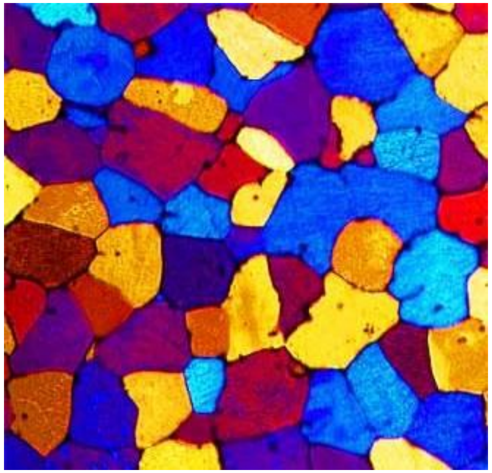
- light is used to study the microstructure
- opaque materials use reflected light, where as transparent materials can use reflected or transmitted light









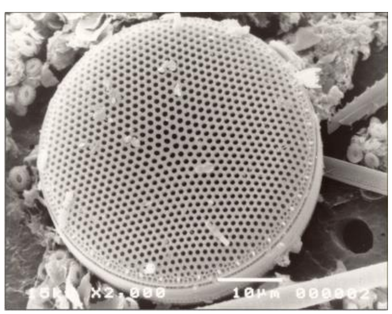


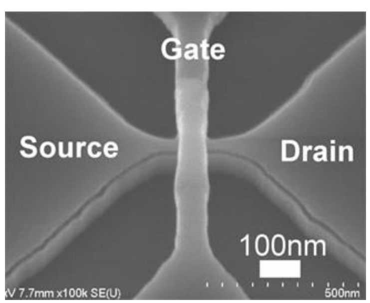
Electron Microscopy

- beams of electrons are used for imaging
- electrons are accelerated across large voltages
- a high velocity electron has a wavelength of about 0.003 nm
- the electron beam is focused and images are formed using magnetic lenses
- reflection and transmission imaging are both possible

Scanning Electron Microscopy (SEM)

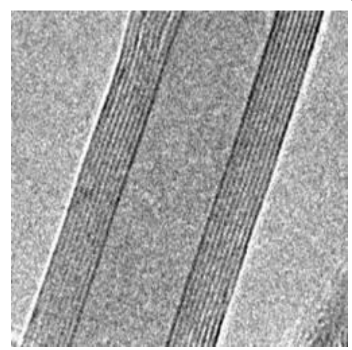
- an electron beam scans the surface and the reflected (backscattered) electrons are collected
- sample must be electrically conductive
- material surface is observed
- 200,000x magnification possible

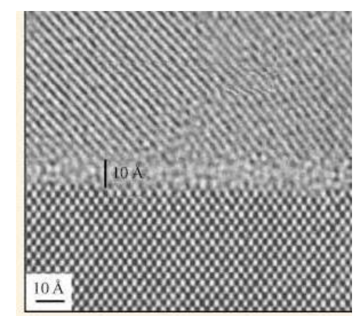




Transmission Electron Microscopy (TEM)

- an electron beam passes through the material
- thin samples
- details of internal microstructure observed
- 1,000,000x magnification possible

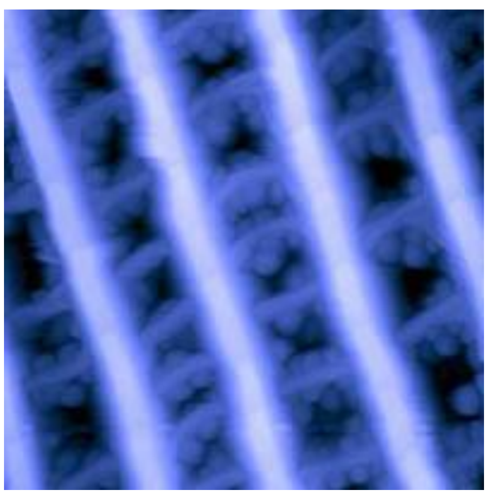




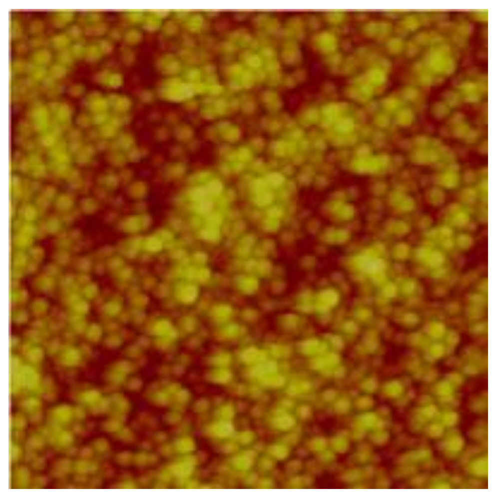
Scanning Probe Microscopy (SPM)

- 3D topographical map of material surface
- probe brought into close proximity of material surface
- probe rastered across the surface experiencing deflection in response to interactions with the material surface
- useful with many different types of materials

Animation of SPM on epitaxial silicon.



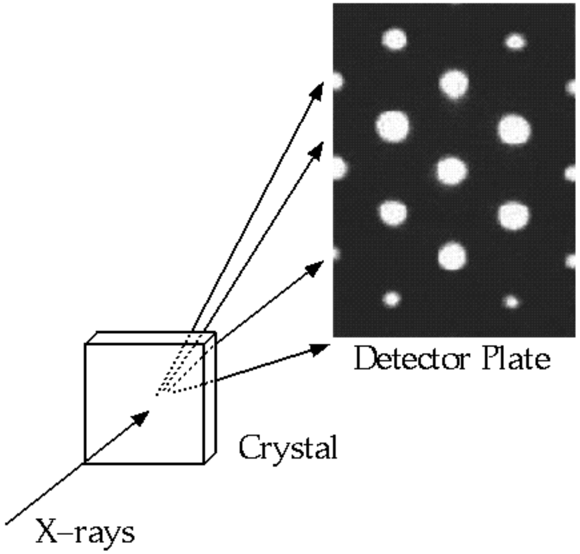
SPM image of a butterfly wing.



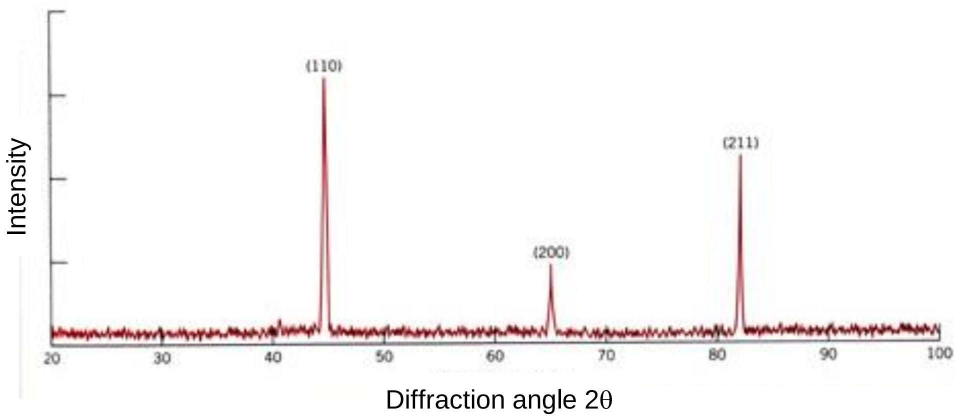
SPM image of silica coated gold nanoparticles.

SPM image of 70 nm photoresist lines.

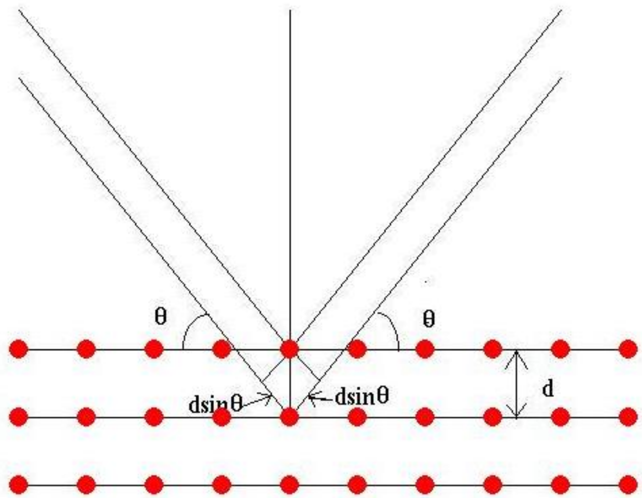
X-ray Diffraction



- x-rays are a form of light that has high energy and short wavelength
- when x-rays strike a material a portion of them are scattered in all directions
- if the atoms in the material is crystalline or well-ordered constructive interference can order



<u>Bragg's</u> Law: $2d \sin \theta = n\lambda$



Material Properties

- **Mechanical**
  - **E.g. Modulus of elasticity, strength**
- **Electrical**
  - **Electrical conductivity, dielectric constant**
- **Thermal**
  - **Thermal expansion, thermal conductivity, heat capacity**
- **Magnetic**
  - **Flux density, susceptibility**
- **Optical**
  - **Index of refraction, reflectivity**
- **Chemical (deteriorative)**
  - **Oxidation, corrosion**
- **Physical Properties**
  - **Density,**

The Materials Selection Process

1. Pick Application → Determine required Properties

   Properties: mechanical, electrical, thermal, magnetic, optical, deteriorative.

2. Properties → Identify candidate Material(s)

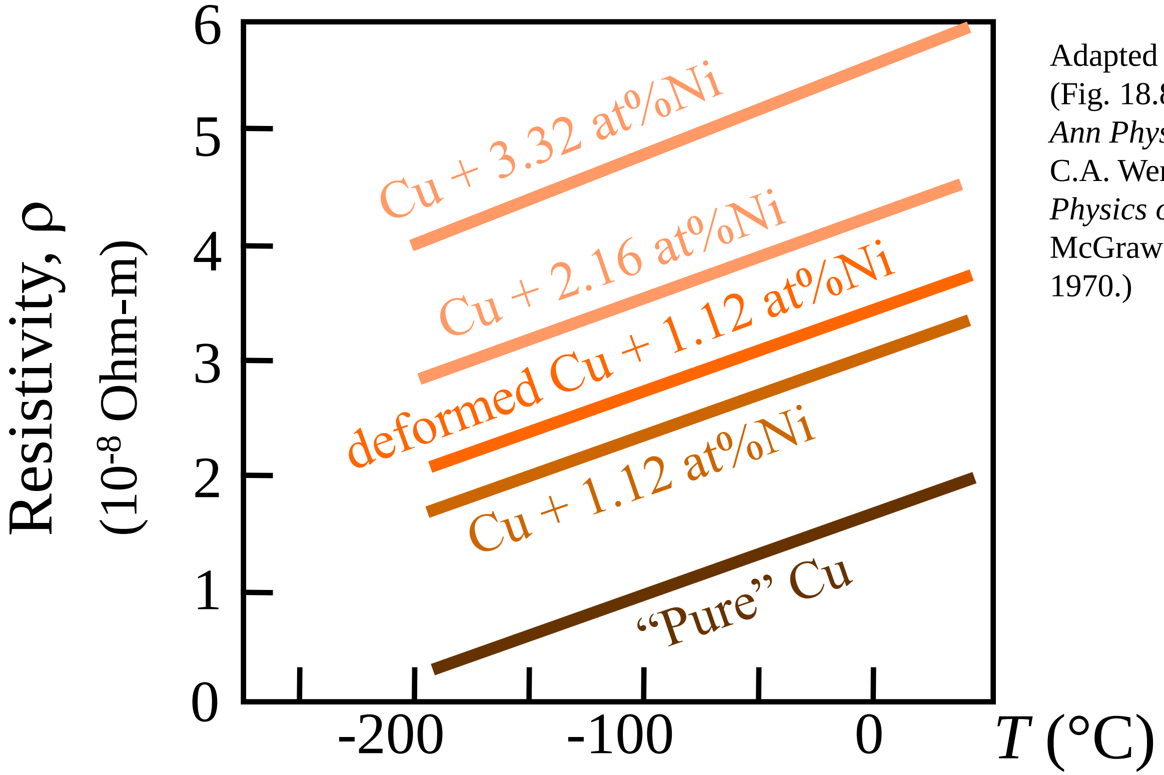
   Material: structure, composition.

3. Material → Identify required Processing

   Processing: changes *structure* and overall *shape*
   ex: casting, sintering, vapor deposition, doping
   forming, joining, annealing.

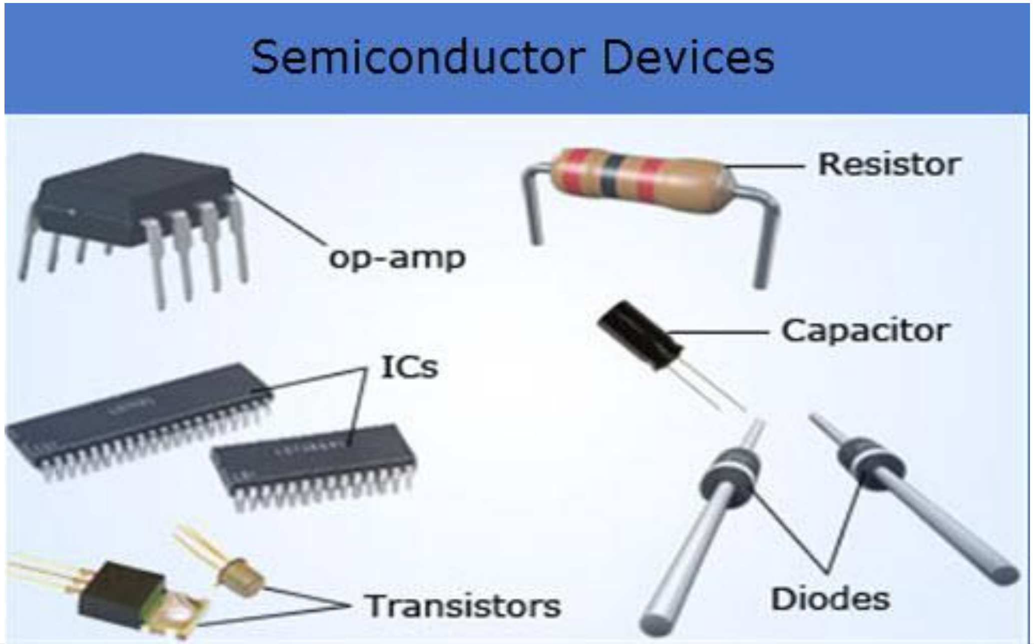
ELECTRICAL PROPERTIES

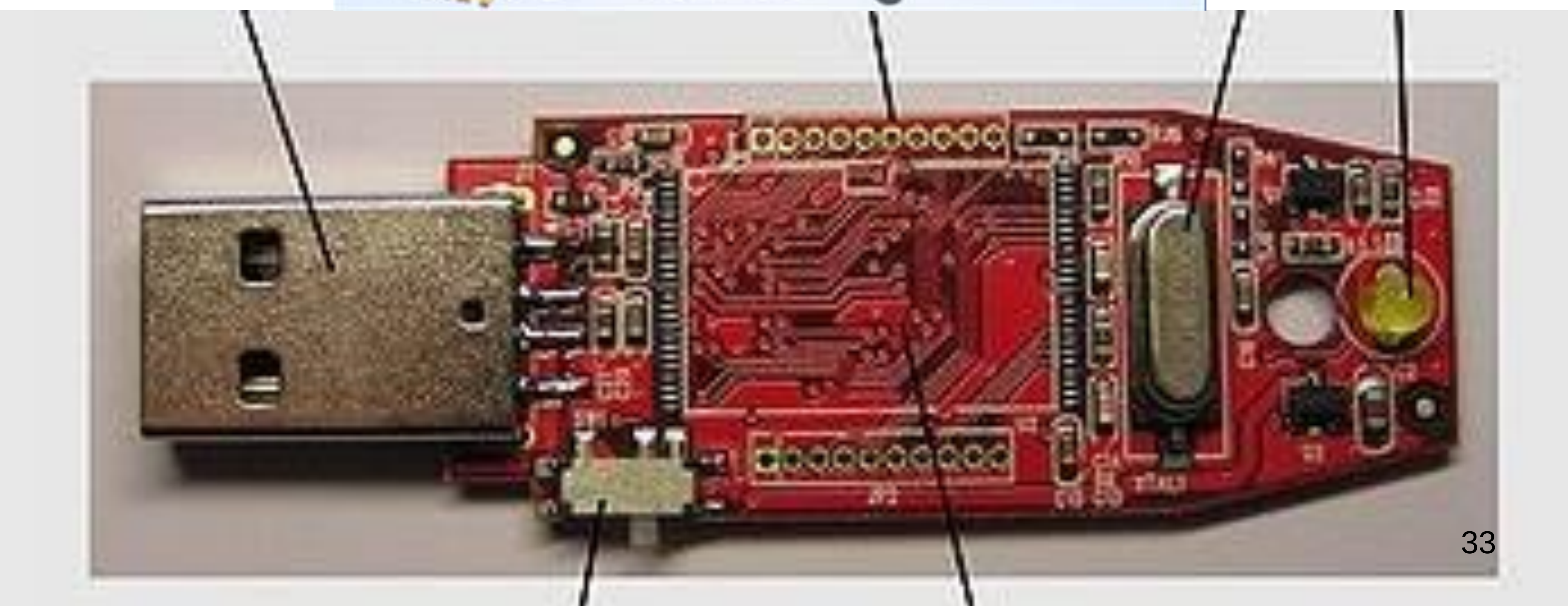
- Electrical Resistivity of Copper:



Adapted from Fig. 18.8, *Callister 7e.* (Fig. 18.8 adapted from: J.O. Linde, *Ann Physik* **5**, 219 (1932); and C.A. Wert and R.M. Thomson, *Physics of Solids*, 2nd edition, McGraw-Hill Company, New York, 1970.)

- Adding "impurity" atoms to Cu increases resistivity.
- Deforming Cu increases resistivity.


Semiconductor Devices
op-amp
Resistor
Capacitor
ICs
Transistors
Diodes



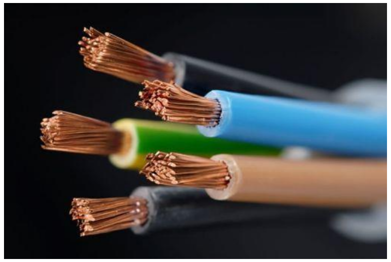
Types of Materials

❑Metals:

Metallic bonding;

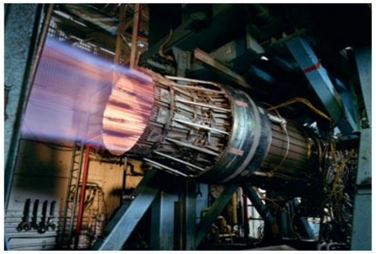
Cu, Al, Ni, Fe, Au, bronze (Cu-Sn), steel (Fe-C) etc.
They are groupped as ferrous (steels) and non-ferrous (copper, magnesium, titanium and so on) metals

<u>Properties:</u> strong, ductile, high density, good conductors of heat and electricity (free valance electrons)



Copper electric wires

Aluminum cup



Jet engine containing mainly titanium alloys

Car body panel: low carbon steel
Engine composed of steel and cast iron parts

Drawback: Corrosion of some metals, i.e. Steel,iron

- Metals
  - Pure metals
    - Iron [Fe]
    - Copper [Cu]
    - Aluminium [Al]
  - Alloys
    - Steel [Fe+C]
    - Brass [Cu+Zn]
    - Bronze [Cu+Sn]
    - Duralumin [Al+Cu]
    - Stainless steel [Fe+C+Cr+Ni],
    - Cast iron [Fe+C]

- **Polymeric (Plastic) Materials**
  - **Organic giant molecules and mostly noncrystalline.**
  - **Some are mixtures of crystalline and noncrystalline regions.**
  - **Poor conductors of electricity and hence used as insulators.**
  - **Strength and ductility vary greatly.**
  - **Low densities and decomposition temperatures.**

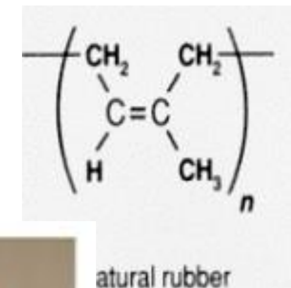
  - ***Examples :-* *Poly vinyl Chloride (PVC), Polyester, PTFE, Nylon***
  - ***Applications :-* *Appliances, DVDs, Fabrics etc.***

❑Polymers:

POLYMER (Greek root)

poly = many meros = part

Organic compounds based on C, H and other nonmetallic elements.
Large molecular structures
(e.g. Epoxy, Nylon, PVC, Polystyrene, Plastics and rubber)
<u>Properties:</u> weak, low density, ductile, extremely flexible,insulators.



Natural Polymers
Rubber, cotton, wool, leather, silk

Synthetic Polymers
PP, PS, PVC, PE

Recyclable plastics

Types of Materials

- **Ceramic Materials**
  - **Metallic and nonmetallic elements are chemically bonded together.**
  - **Inorganic but can be either crystalline, noncrystalline or mixture of both.**
  - **High hardness, strength and wear resistance.**
  - **Very good insulator. Hence used for furnace lining for heat treating and melting metals.**
  - **Also used in space shuttle to insulate it during exit and reentry into atmosphere.**
  - **Other applications : Abrasives, construction materials, utensils etc.**

  - ***Example:- Porcelain, Glass, Silicon nitride.***

❑Ceramics:

Combinations of metals or with oxygen, nitrogen, carbon and boron (oxides, nitrides, carbides, borides) CaO, Al_2O_3, BN, SiC, TiB_2

<u>Properties:</u> hard but very brittle, Insulators of heat and electricity, resistant to high temperature and harsh environments,

Whiteware

1-TRADITIONAL CERAMICS

Pottery, porcelain, brick, glass

2-ADVANCED CERAMICS

Structural: **bioceramics, cutting tools, engine components, armour.**

Electrical: **Capacitors, insulators, magnets and superconductors**

Brake disc

SiC engine components

SiC body armour

Cutting tools

Types of Materials

Composite Materials

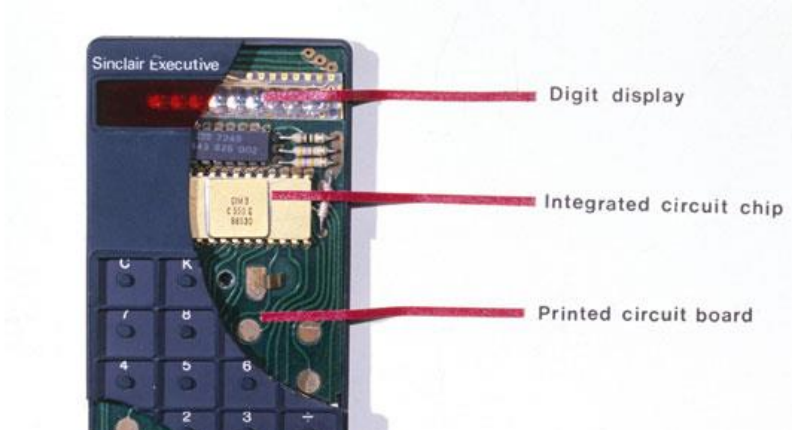
– Mixture of two or more materials.
– Consists of a filler material and a binding material.
– Materials only bond, will not dissolve in each other.
– Mainly two types :-
  - Fibrous: Fibers in a matrix
  - Particulate: Particles in a matrix
– Matrix can be metals, ceramic or polymer
– *Examples :*
  - Fiber Glass (Reinforcing material in a polyester or epoxy matrix)
  - Concrete (Gravels or steel rods reinforced in cement and sand)
– *Applications*:- Aircraft wings and engine, construction.

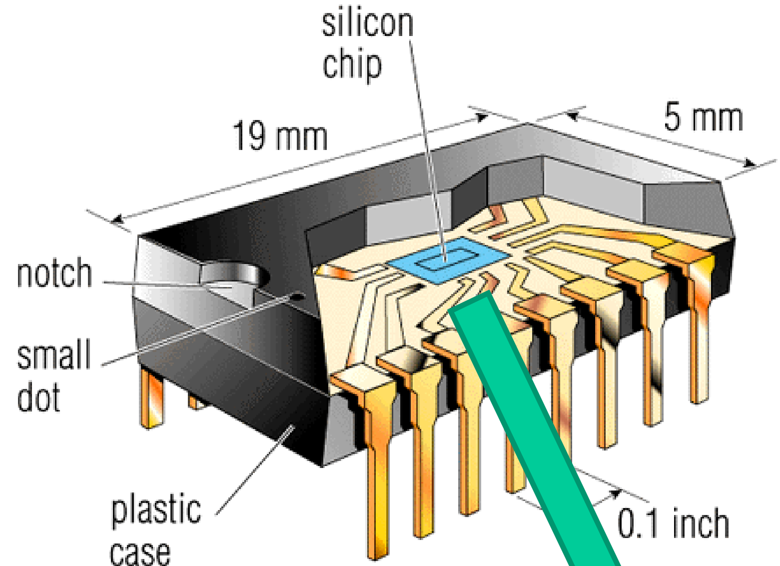
Foundations of Mat. Sci. and Eng. W.Smith, J. Hashemi, McGraw Hill
http://highered.mcgraw-hill.com/

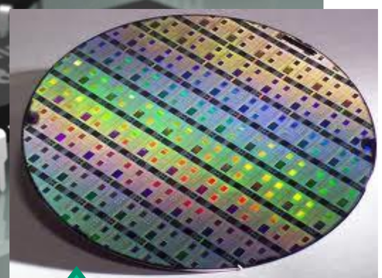
Types of Materials

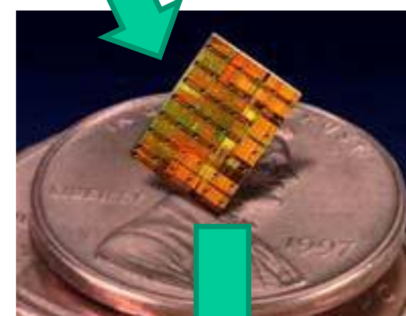
Electronic Materials

- Not Major by volume but very important.
- Silicon is a common electronic material.
- Its electrical characteristics are changed by adding impurities.
- *Examples:-* Silicon chips, transistors
- *Applications :-* Computers, Integrated Circuits, Satellites etc.

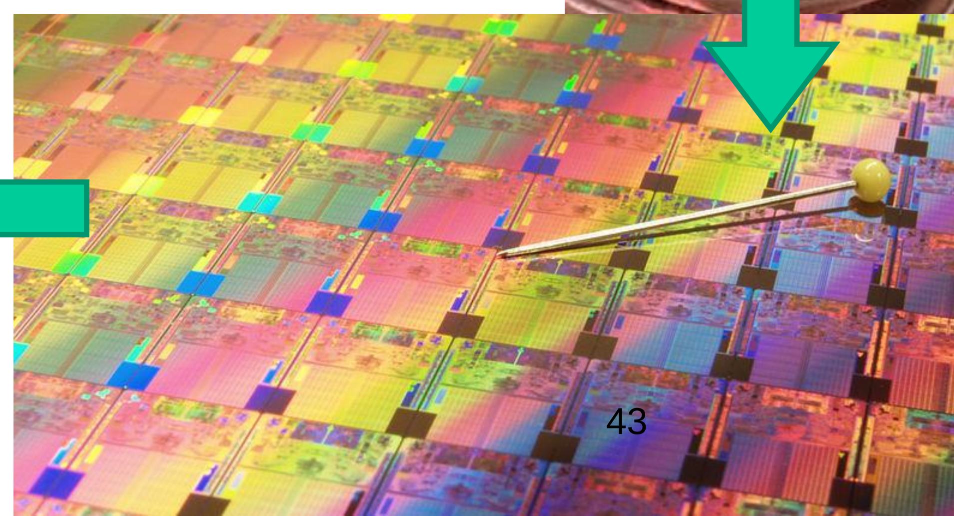




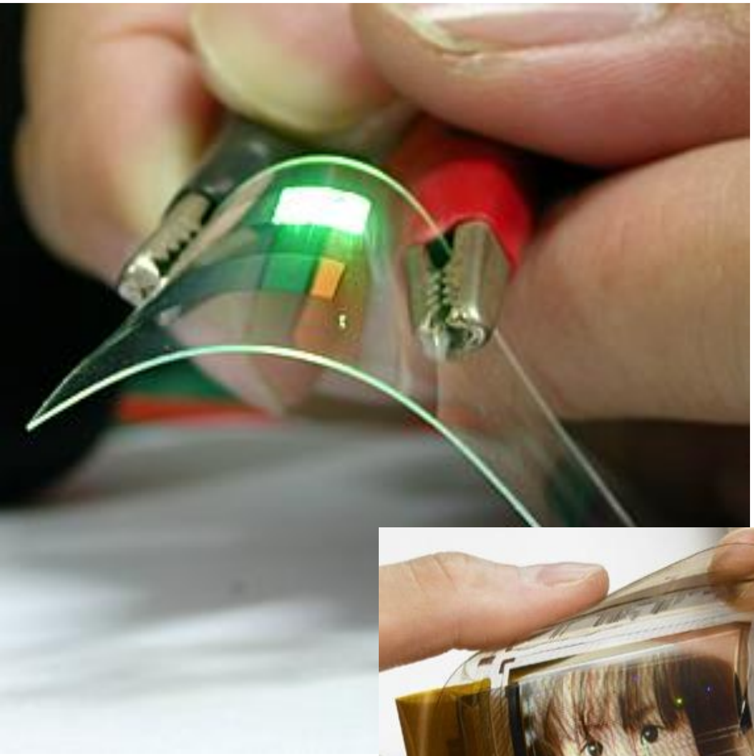




Smaller and thinner than a dime, this tiny silicon chip contains millions of transistors that work together



SEMICONDUCTORS

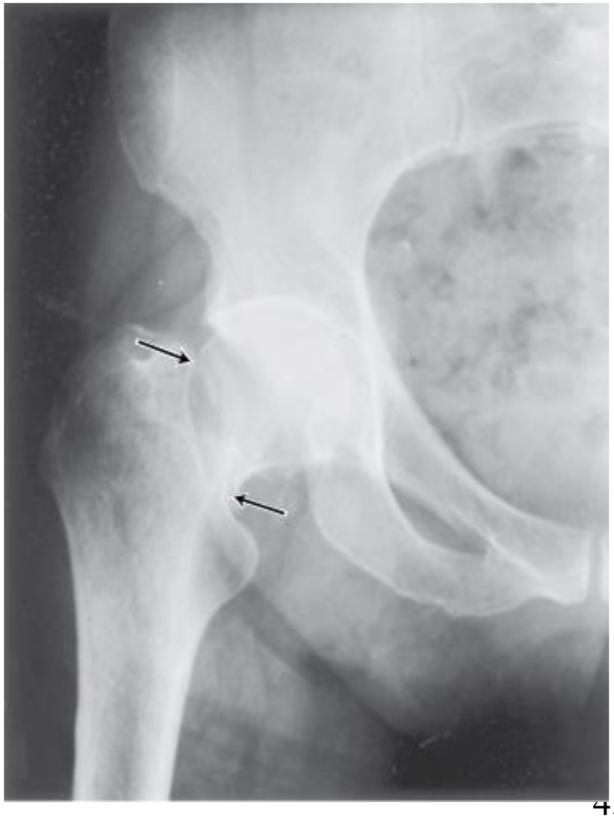


Solar Cells

OLED Technology

Example – Hip Implant

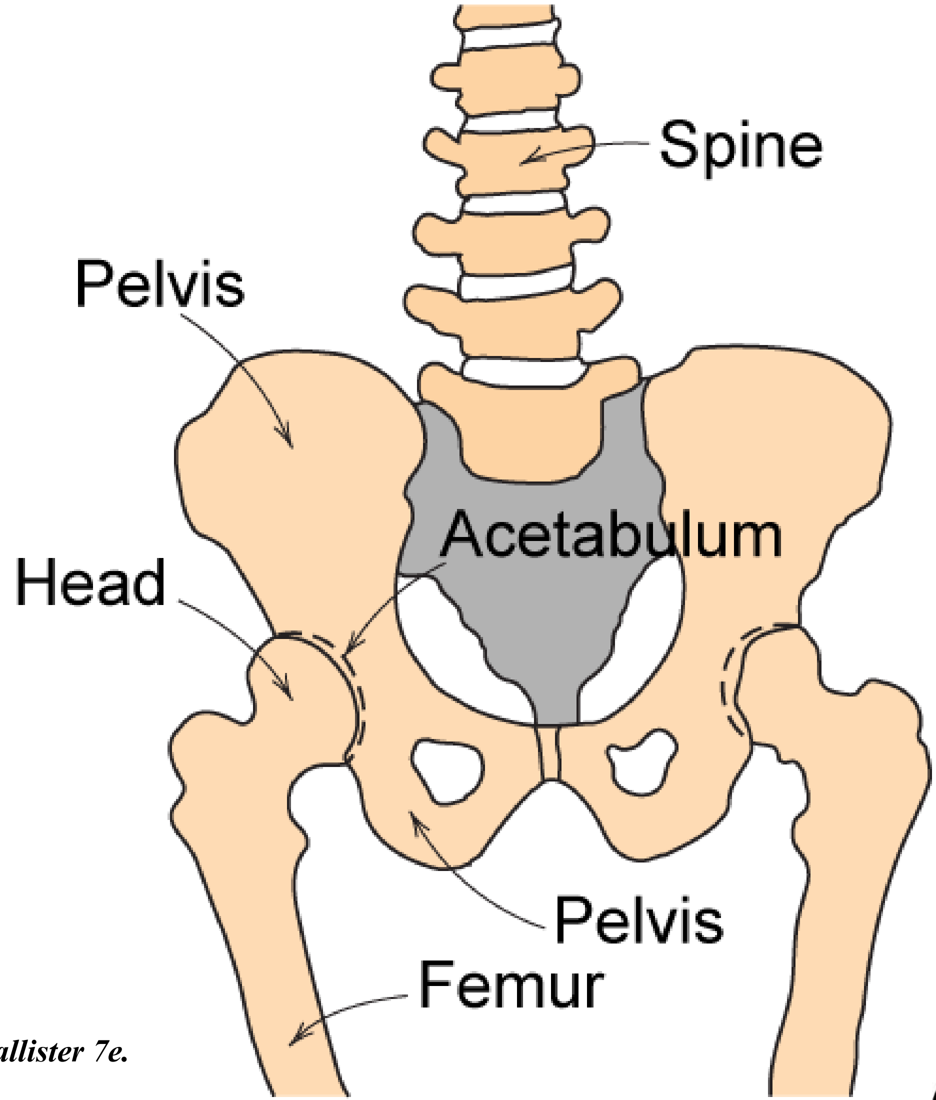
- With age or certain illnesses joints deteriorate. Particularly those with large loads (such as hip).



Adapted from Fig. 22.25, *Callister 7e.*

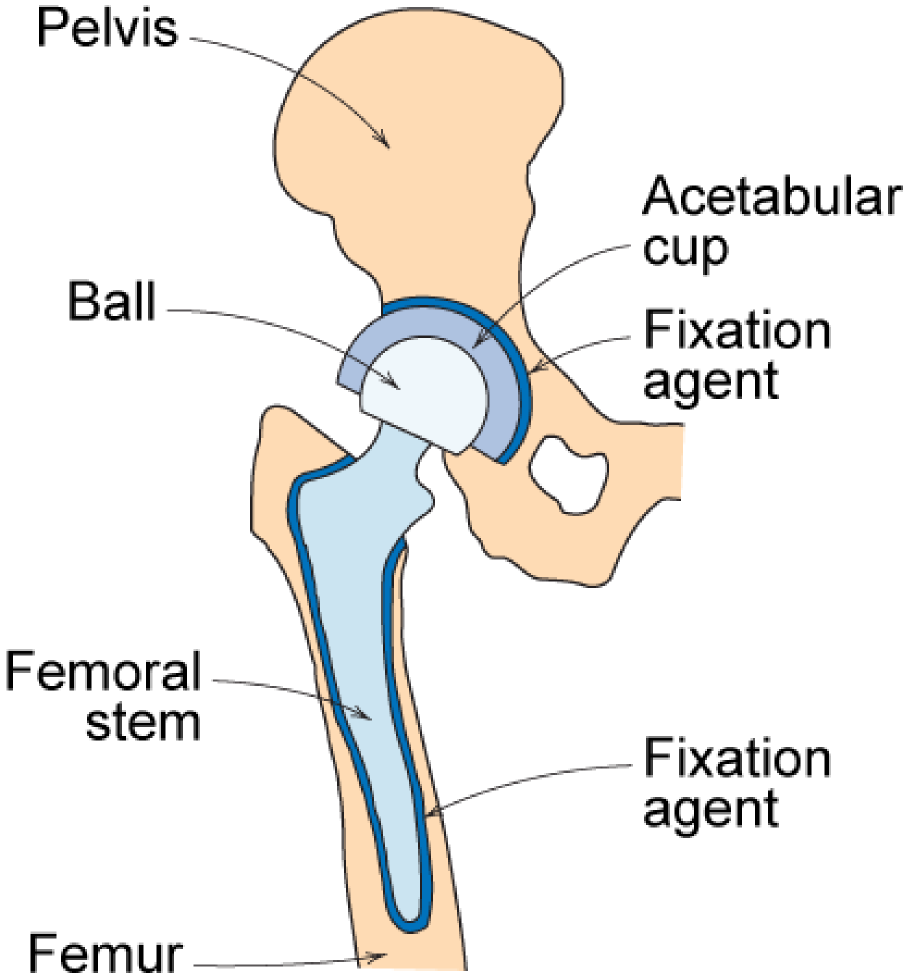
Example – Hip Implant

- Requirements
  - mechanical strength (many cycles)
  - good lubricity
  - biocompatibility



Adapted from Fig. 22.24, *Callister 7e.*

Example – Hip Implant



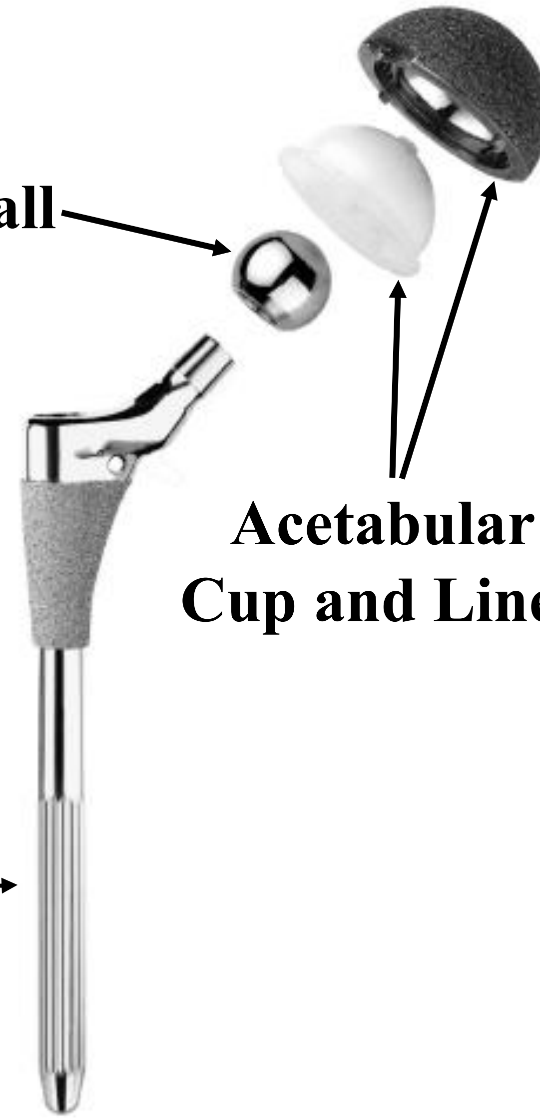
(a)

(b)

Adapted from Fig. 22.26, *Callister 7e.*

Hip Implant

- Key problems to overcome
  - fixation agent to hold acetabular cup
  - cup lubrication material
  - femoral stem – fixing agent (“glue”)
  - must avoid any debris in cup



Adapted from chapter-opening photograph, Chapter 22, *Callister 7e.*

Competition Among Materials

- Materials compete with each other to exist in new market
- Over a period of time usage of different materials changes depending on cost and performance.
- New, cheaper or better materials replace the old materials when there is a breakthrough in technology

Example:-

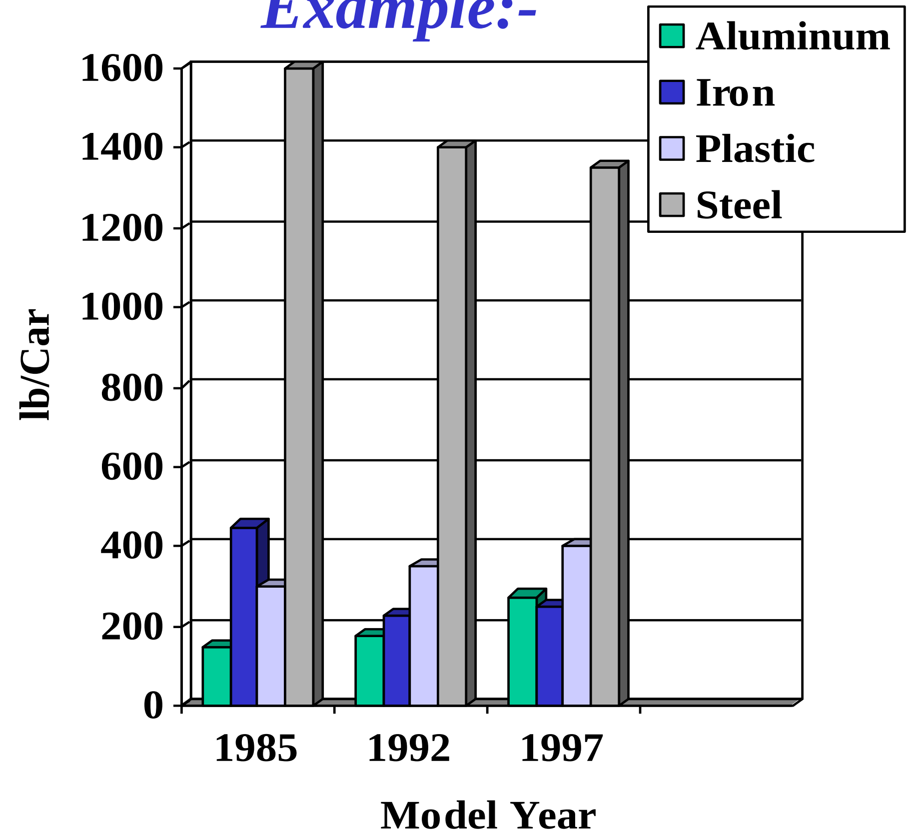
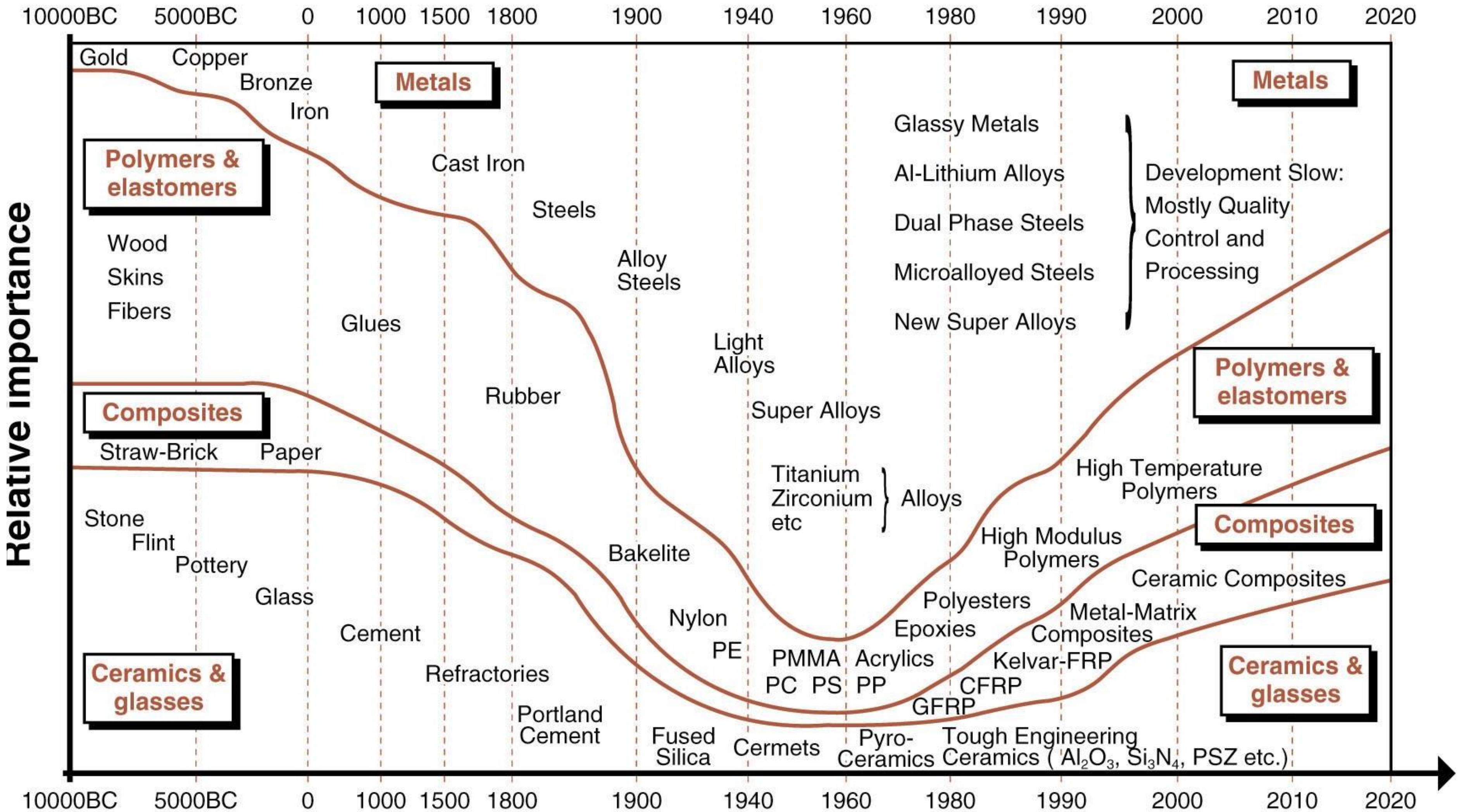


Figure 1.14

Predictions and use of materials in US automobiles.

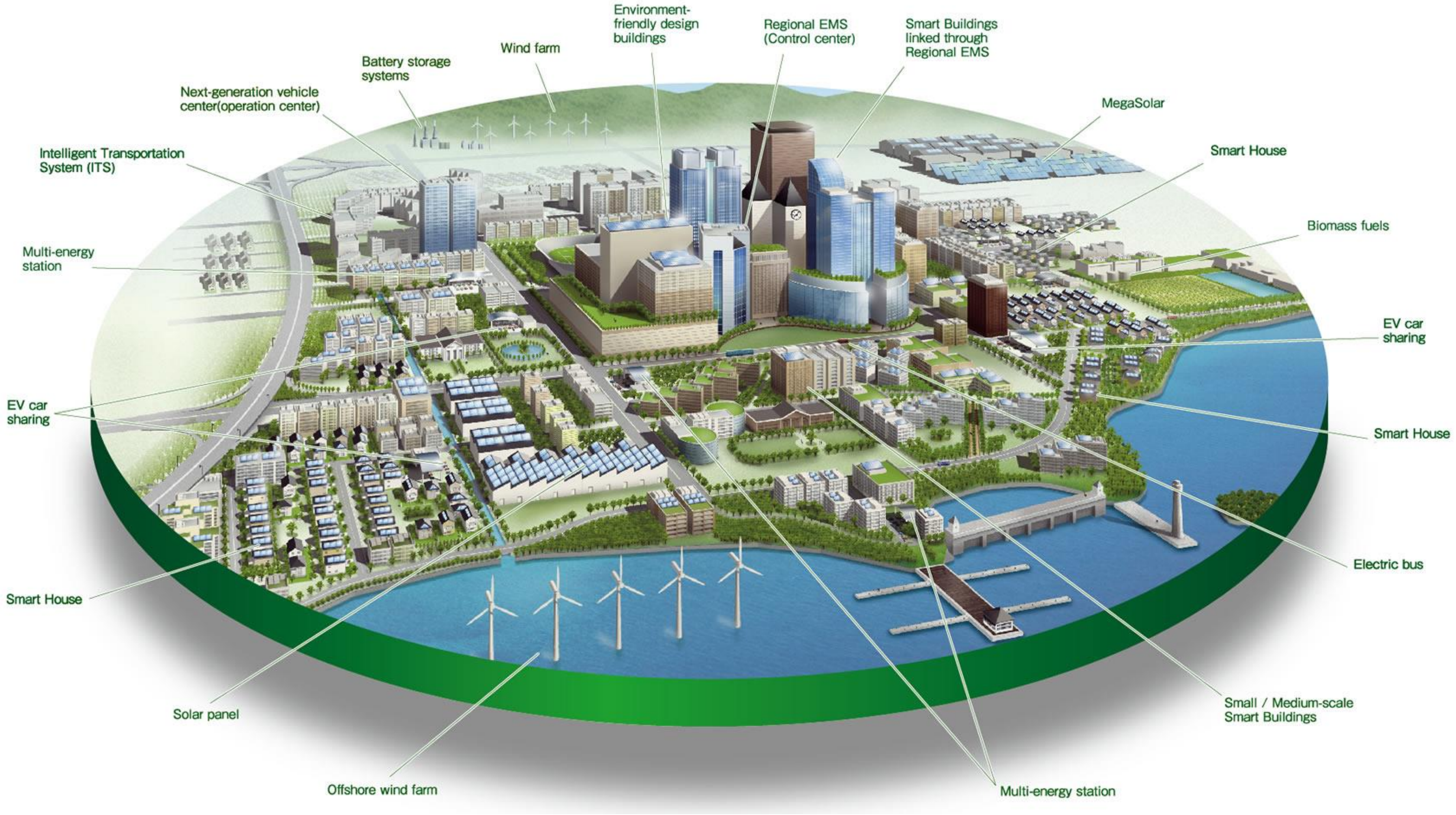
After J.G. Simon, Adv. Mat. & Proc., 133:63(1988) and new data

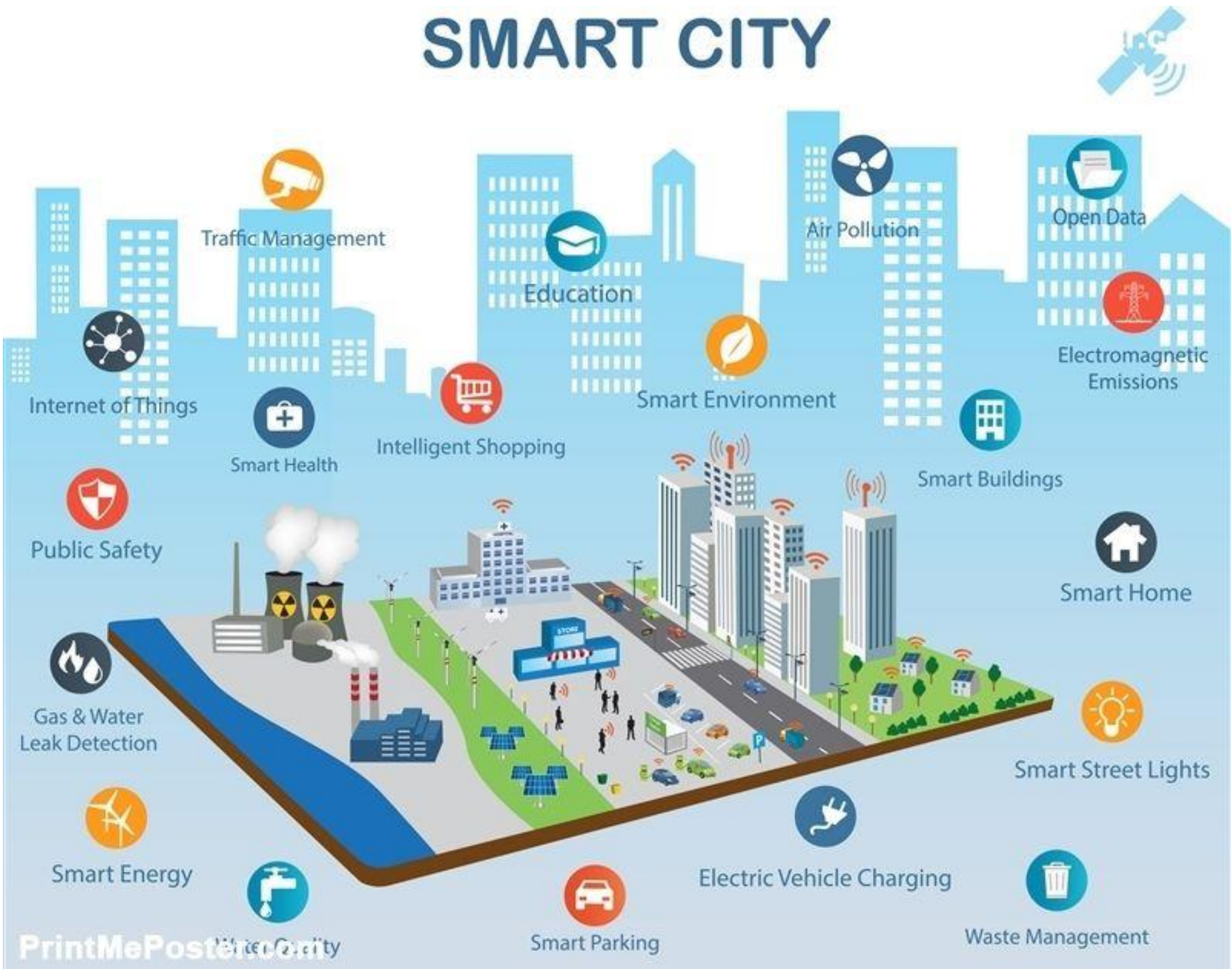

10000BC 5000BC 0 1000 1500 1800 1900 1940 1960 1980 1990 2000 2010 2020
Relative importance
Metals
Polymers & elastomers
Composites
Ceramics & glasses
Gold
Copper
Bronze
Iron
Cast Iron
Steels
Alloy Steels
Light Alloys
Super Alloys
Titanium
Zirconium
etc
Alloys
Glassy Metals
Al-Lithium Alloys
Dual Phase Steels
Microalloyed Steels
New Super Alloys
Development Slow:
Mostly Quality
Control and
Processing
Wood
Skins
Fibers
Glues
Rubber
Bakelite
Nylon
PE
PMMA
PC
PS
Acrylics
PP
Polyesters
Epoxies
High Modulus Polymers
High Temperature Polymers
Straw-Brick
Paper
GFRP
CFRP
Kelvar-FRP
Metal-Matrix Composites
Ceramic Composites
Stone
Flint
Pottery
Glass
Cement
Refractories
Portland Cement
Fused Silica
Cermets
Pyro-Ceramics
Tough Engineering Ceramics (Al_2O_3, Si_3N_4, PSZ etc.)

Advanced Materials

- High tech Materials-(intricate and sophisticated principles)
  - Materials used for laser Technology
  - Integrated circuits
  - Magnetic information storage
  - Liquid crystal displays
  - Fiber optics
  - Aerospace applications
- Smart Materials-(Material properties change with the environment in a predetermined manner) used in sensors and actuators
  - Shape memory alloys
  - Piezoelectric ceramics
  - Magnetostrictive materials
  - Electrorhelogical/magnetorhelogical fluids
- **NanoTechnology**

Sustainable city concept



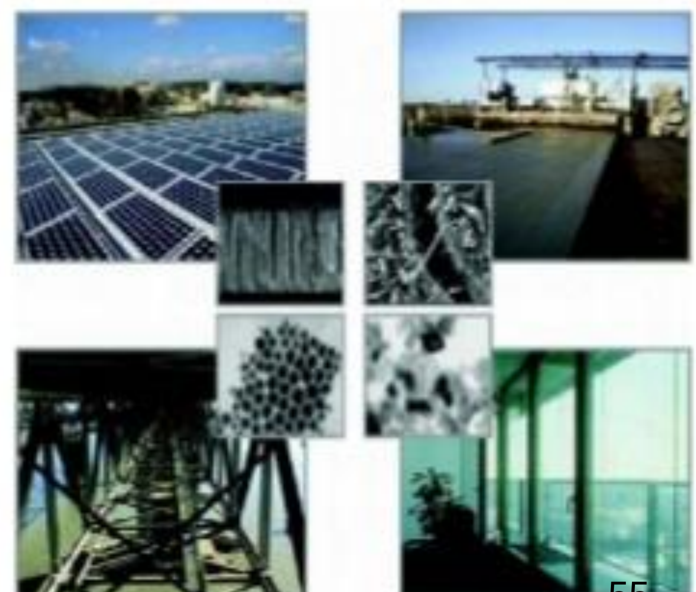

SMART CITY
Traffic Management
Education
Air Pollution
Open Data
Internet of Things
Smart Health
Intelligent Shopping
Smart Environment
Electromagnetic Emissions
Smart Buildings
Public Safety
Smart Home
Gas & Water Leak Detection
Smart Street Lights
Smart Energy
Electric Vehicle Charging
Smart Parking
Waste Management
PrintMePosters.com


OPERATIONS CONTROL
PUBLIC ANNOUNCEMENT
WATER MANAGEMENT
WEATHER SENSORS
IoT CONTROL
ANALYTICS
CCTV SURVEILLANCE
3D MAP & INTERACTION
ENERGY CONTROL
PEOPLE TRACKING
INVENTORY/WORKFLOW MONITORING
WASTE MANAGEMENT
IoT enabled Smart City
PARKWIDE WiFi
SMART PARKING
EMERGENCY SYSTEMS
SMART METERING
Ad
DIGITAL SIGNAGE
POLLUTION

Applications of Nano-technology

Nanotechnology is widely used in construction material as:

- In Concrete
- In Steel
- In Wood
- In Glass
- In Coating
- In photovoltaic



Existing applications   Possible future applications

Application / Effect	Functionalities	Car body shell exterior	Car body	Interior	Chassis and tyres	Electrics and electronics	Engine and drive train
Mechanical functionalities	Hardness, friction, tribological properties, breaking resistance	Nano varnish			Carbon black in tyres		Low-friction aggregate components
		Polymer glazing	Nanosteel		Nanosteel		
Geometric effects	Large surface-to-volume ratio, Poresize			Nano filter		Super caps	
			Gecko effect	Gecko effect		Fuel cell	
Electronic/ magnetic functionalities	Size dependent electric and magnetic properties		Gluing on command			GMR sensors	Piezo injectors
					Switchable materials (rheology)	Solar cells	
Optical functionalities	Colour, fluorescence, transparency	Ultra-thin layers		Anti-glare coatings			
		Electro chromatic layers					
Chemical functionalities	Reactivity, selectivity, surface properties	Care and sealing systems	Forming of high strength steel	Dirt protection			Catalysts
			Corrosion protection	Fragrance in the cabin			Fuel additives

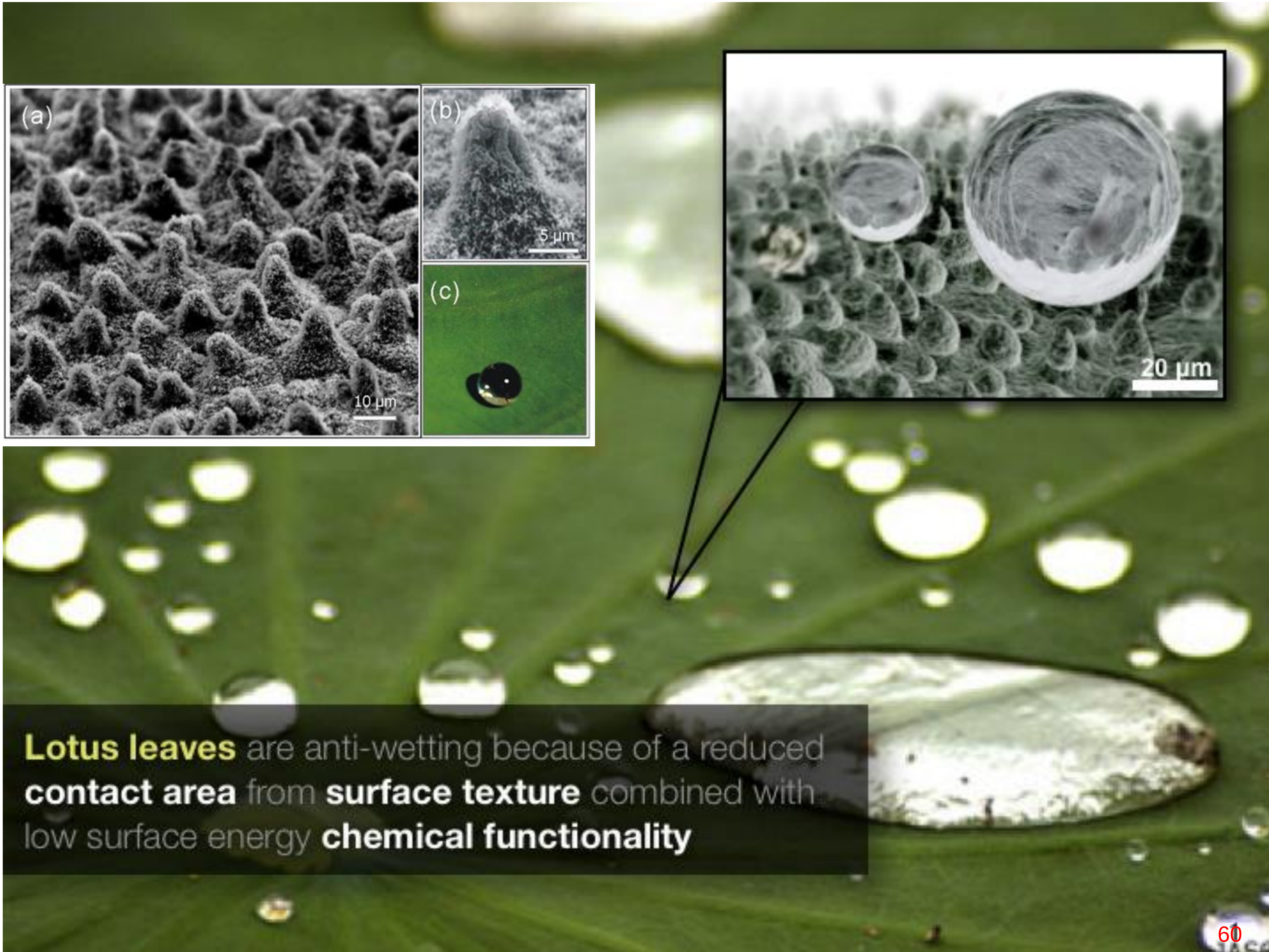
Ref: www.slintec.lk


NANOTECHNOLOGY BASED
WATER PURIFICATION SOLUTIONS

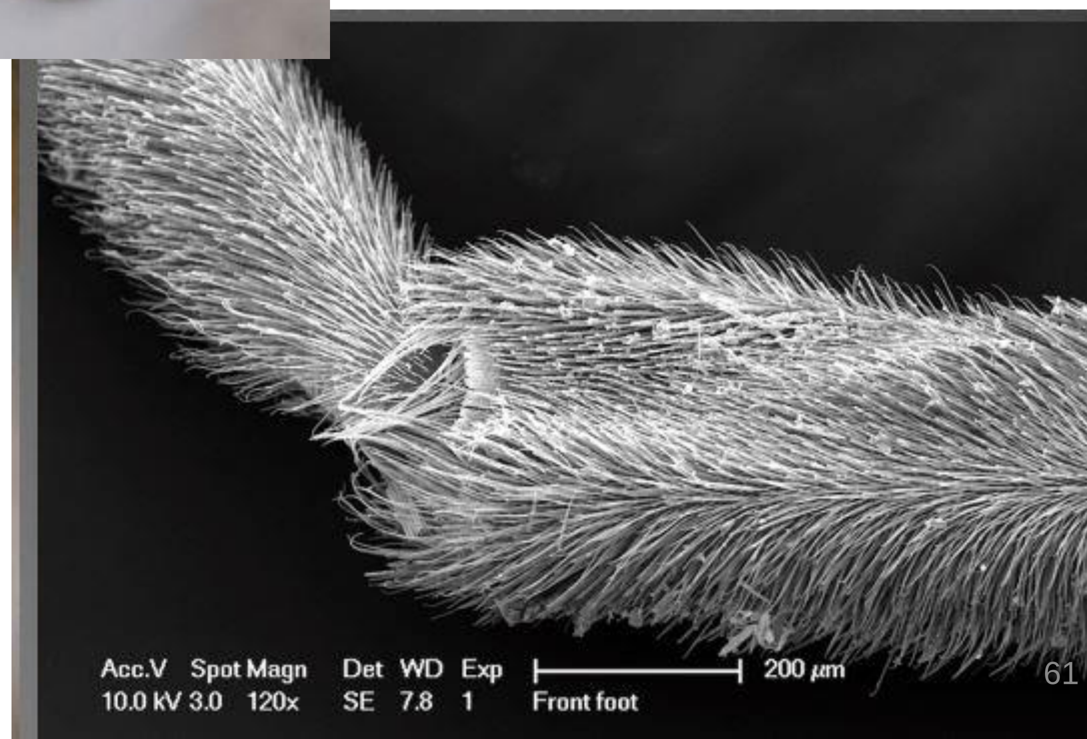
BIOMIMETICS

Some paints and roof tiles have been engineered to be self-cleaning by copying the mechanism from the lotus

Lotus leaf surface


(a)
10 µm
(b)
5 µm
(c)
20 µm
Lotus leaves are anti-wetting because of a reduced contact area from surface texture combined with low surface energy chemical functionality

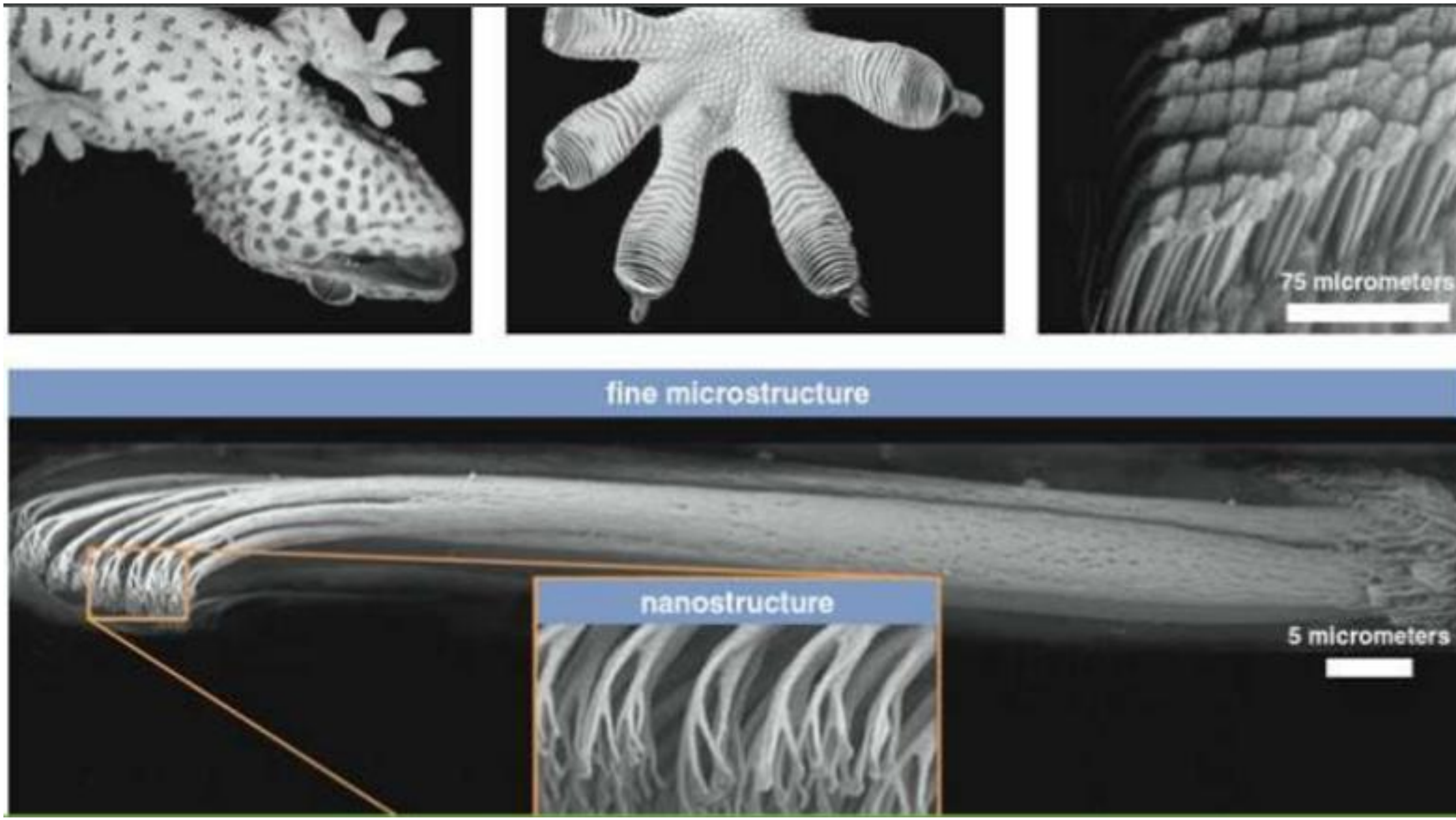
Water strider



A force similar to surface tension, called van der Waals, lets geckos walk on walls!

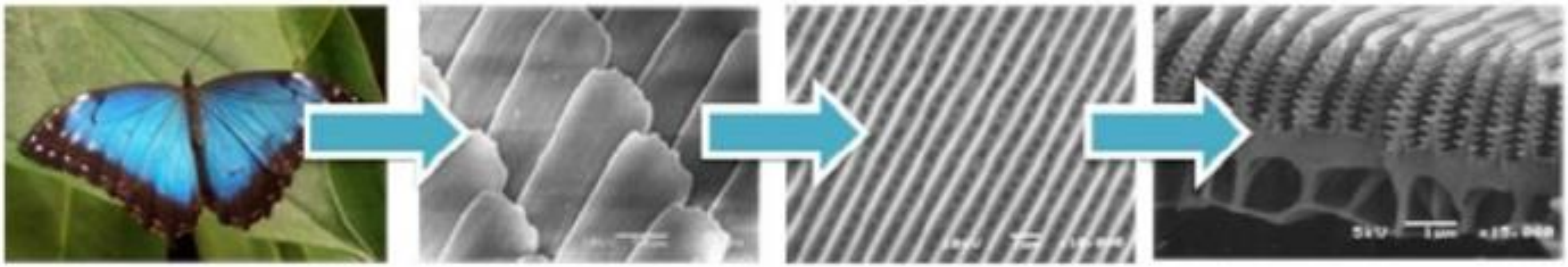
How is this nano?

Different physical forces dominate when things get very, very small. For example, gravity is very obvious at human size, but it's hardly noticeable to nano-sized things like water molecules. Other forces (like surface tension) are much more important.


75 micrometers
fine microstructure
nanostructure
5 micrometers


Case of Butterfly
The wings of Butterflies often display extra ordinary colours which are a consequence of the wings' surface and its interaction with light.
It also exhibits the phenomenon of IRIDESCENCE.

SEM Analysis of Wings



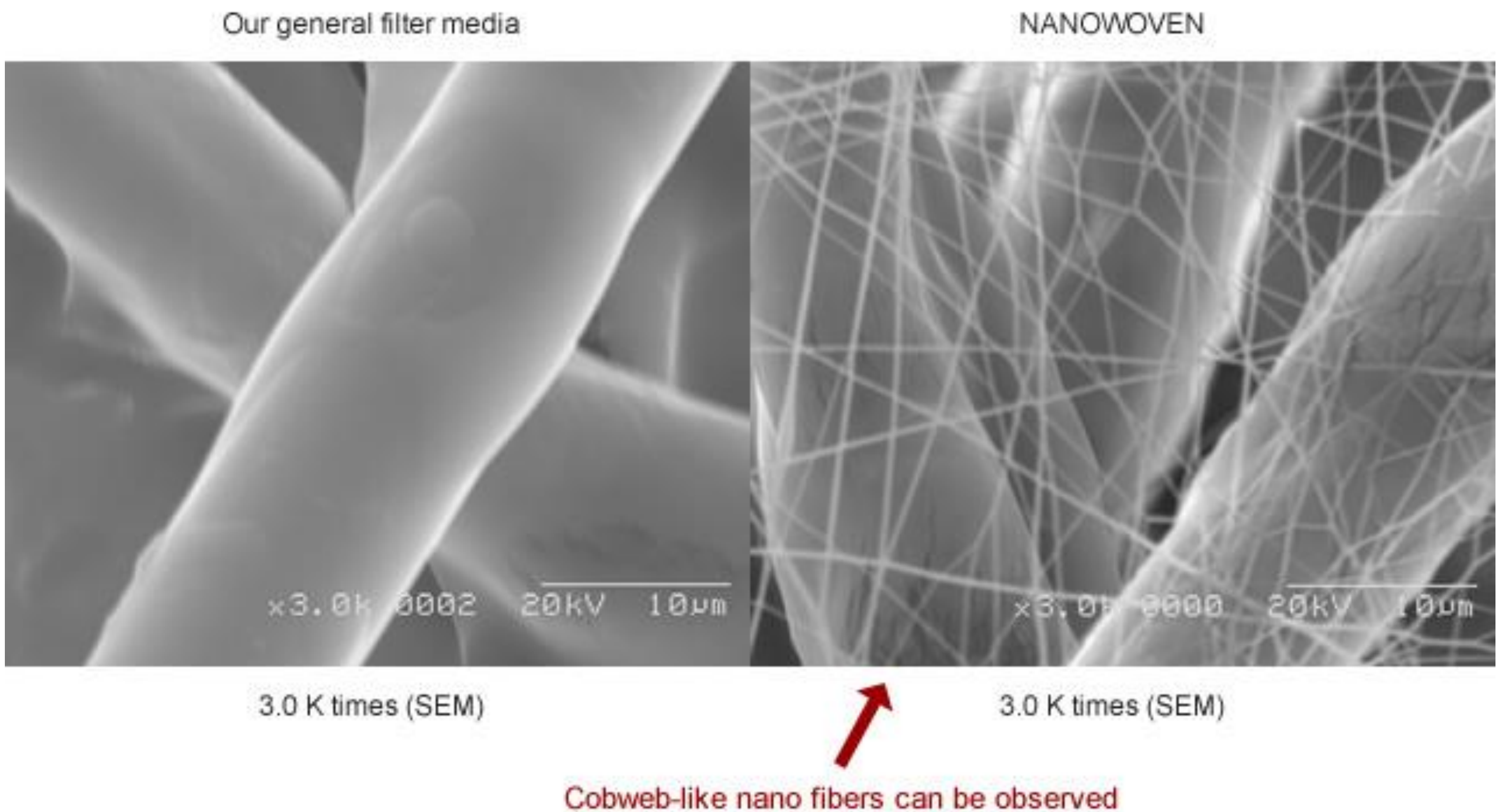
- Shows even more intricate structure called SETAE : looks like fir trees
- About 400 nm long, responsible for producing constructive interference in blue wavelengths which generates strong blue colour.

Toucan's Beak: Strong a and light

Despite its large size (a third of the length of the bird) and considerable strength, the toucan beak comprises only one twentieth the bird's mass.

While the large strong beak is useful in foraging, defense and attracting mates, its low density is essential for the toucan to retain its ability to fly.

cobweb



Our general filter media
NANOWOVEN
×3.0k 0002 20kV 10μm
3.0 K times (SEM)
3.0 K times (SEM)
Cobweb-like nano fibers can be observed

Biomimetic material	Inspired from
Adhesives	Gecko's feet
High tensile strength fibre	Spider silk
Dirt and water resistant paint	Lotus leaf
IMOD Display technology	Butterfly wings
Reduced drag suits for athletes	Shark skin
Structural elements	Wood, ligaments and bone
Aerospace and automotive applications	Toucan's beak

SOME CURRENT APPLICATIONS OF NANOTECHNOLOGY

SOLAR CELLS

Nanotechnology enhancements provide:

- **Improved efficiencies: novel nanomaterials can harness more of the sun's energy**
- **Lower costs: some novel nanomaterials can be made cheaper than alternatives**
- **Flexibility: thin film flexible polymers can be manipulated to generate electricity from the sun's energy**

COMPUTING

Nanotechnology enhancements provide:

- **Faster processing speeds: miniaturization allows more transistors to be packed on a computer chip**
- **More memory: nanosized features on memory chips allow more information to be stored**
- **Thermal management solutions for electronics: novel carbon-based nanomaterials carry away heat generated by sensitive electronics**

CLOTHING

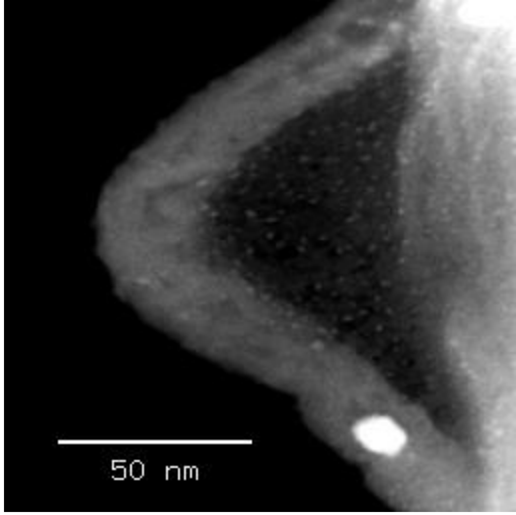
Nanotechnology enhancements provide:

- **Anti-odor properties: silver nanoparticles embedded in textiles kill odor causing bacteria**
- **Stain-resistance: nanofiber coatings on textiles stop liquids from penetrating**
- **Moisture control: novel nanomaterials on fabrics absorb perspiration and wick it away**
- **UV protection: titanium nanoparticles embedded in textiles inhibit UV rays from penetrating through fabric**

BATTERIES

Nanotechnology enhancements provide:

- **Higher energy storage capacity and quicker recharge: nanoparticles or nanotubes on electrodes provide high surface area and allow more current to flow**
- **Longer life: nanoparticles on electrodes prevent electrolytes from degrading so batteries can be recharged over and over**
- **A safer alternative: novel nano-enhanced electrodes can be less flammable, costly and toxic than conventional electrodes**



SPORTING GOODS AND EQUIPMENT

Nanotechnology enhancements provide:

- **Increased strength of materials: novel carbon nanofiber or nanotube-based nanocomposites give the player a stronger swing**
- **Lighter weight materials: nanocomposites are typically lighter weight than their macroscale counterparts**

CARS

Nanotechnology enhancements provide:

- **Increased strength of materials: novel carbon nanofiber or nanotube nanocomposites are used in car bumpers, cargo liners and as step-assists for vans**
- **Lighter weight materials: lightweight nanocomposites mean less fuel is used to make the car go**
- **Control of surface characteristics: nanoscale thin films can be applied for optical control of glass, water repellency of windshields and to repair of nicks/scratches**

FOOD AND BEVERAGE

Nanotechnology enhancements provide:

- Better, more environmentally friendly adhesives for fast food containers
- Anti-bacterial properties: Nano silver coatings on kitchen tools and counter-tops kill bacteria/microbes

- Improved barrier properties for carbonated beverages or packaged foods: nanocomposites slow down the flow of gas or water vapor across the container, increasing shelf life

THE ENVIRONMENT

Nanotechnology enhancements provide:

- **Improved ability to capture groundwater contaminants: nanoparticles with high surface area are injected into groundwater to bond with contaminants**
- **Replacements for toxic materials**

BODY ARMOR

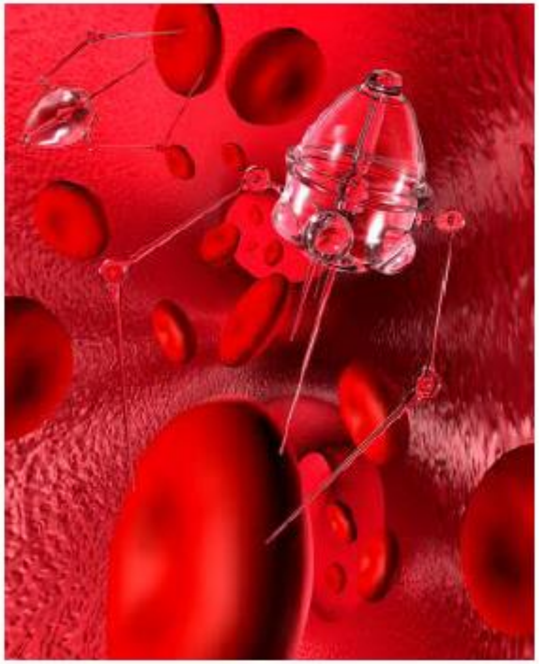
Nanotechnology enhancements will provide:

- **Stronger materials for better protection: nanocomposites that provide unparalleled strength and impact resistance**
- **Flexible materials for more form-fitting wearability: nanoparticle-based materials that act like "liquid armor"**
- **Lighter weight materials: nanomaterials typically weigh less than their macroscale counterparts**
- **Dynamic control: nanofibers that can be flexed as necessary to provide CPR to soldiers or stiffen to furnish additional protection in the face of danger**

DRUG DELIVERY

Nanotechnology enhancements will provide:

- **New vehicles for delivery: nanoparticles such as buckyballs or other cage-like structures that carry drugs through the body**
- **Targeted delivery: nano vehicles that deliver drugs to specific locations in body**
- **Time release: nanostructured material that store medicine in nanosized pockets that release small amounts of drugs over time**



CANCER

Nanotechnology enhancements will provide:

- **Earlier detection: specialized nanoparticles that target cancer cells only – these nanoparticles can be easily imaged to find small tumors**
- **Improved treatments: infrared light that shines on the body is absorbed by the specialized nanoparticles in the cancer cells only, leading to an increased localized temperature that selectively kills the cancer cells but leaves normal cells unharmed**

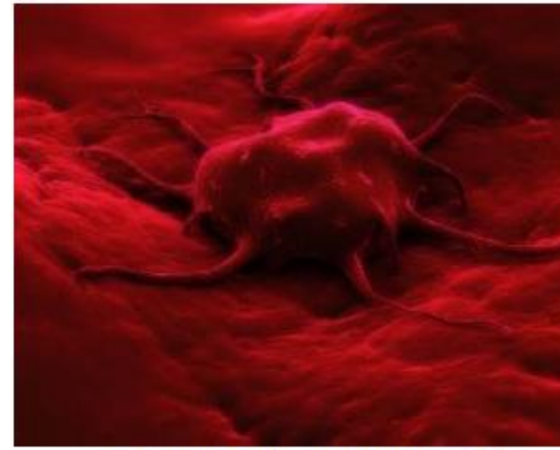
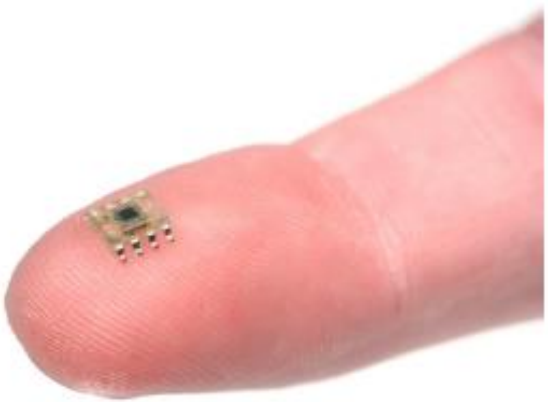


Image of a cancer cell

SENSORS

Nanotechnology enhancements will provide:

- **Higher sensitivity: high surface area of nanostructures that allows for easier detection of chemicals, biological toxins, radiation, disease, etc.**



- **Miniaturization: nanoscale fabrication methods that can be used to make smaller sensors that can be hidden and integrated into various objects**

NEXT GENERATION COMPUTING

Nanotechnology enhancements will provide:

- The ability to control atomic scale phenomena: quantum or molecular phenomena that can be used to represent data
- Faster processing speeds
- Lighter weight and miniaturized computers
- Increased memory
- Lower energy consumption

NANOROBOTICS

Nanotechnology enhancements will provide:

- Miniaturized fabrication of complex nanoscale systems: nanorobots that propel through the body and detect/ cure disease or clandestinely enter enemy territory for a specific task
- Manipulation of tools at very small scales: nanorobots that help doctors perform sensitive surgeries

WATER PURIFICATION

Nanotechnology enhancements will provide:

- Easier contamination removal: filters made of nanofibers that can remove small contaminants
- Improved desalination methods: nanoparticle or nanotube membranes that allow only pure water to pass through
- Lower costs
- Lower energy use

MORE ENERGY/ENVIRONMENT APPLICATIONS…

Nanotechnology enhancements will provide:

- Improvements to solar cells
- Improvements to batteries
- Improvements to fuel cells
- Improvements to hydrogen storage
- CO_2 emission reduction: nanomaterials that do a better job removing CO_2 from power plant exhaust
- Stronger, more efficient power transmission cables: synthesized with nanomaterials

Future Trends

- **Smart Materials :** **Change their properties by sensing external stimulus.**
  - **Shape memory alloys: Strained material reverts back to its original shape above a critical temperature.**
    - **Used in heart valves and to expand arteries.**
  - **Piezoelectric materials: Produce electric field when exposed to force and vice versa.**
    - **Used in actuators and vibration reducers.**

MEMS and Nanomaterials

- MEMS: Microelectromechanical systems.
  - Miniature devices
  - Micro-pumps, sensors

- Nanomaterials: Characteristic length < 100 nm
  - Examples: ceramics powder and grain size < 100 nm
  - Nanomaterials are harder and stronger than bulk materials.
  - Have biocompatible characteristics (as in Zirconia)
  - Transistors and diodes are developed on a nanowire.

Modern Materials Needs

- In the field of Nuclear Energy
  - Environmental issues
  - Disposal of radioactive waste
- Transportation
  - Energy and environmental issues
- Energy
  - Advanced Solar cells
  - Light emitting diodes - LEDs
- Pollution control
  - Catalytic converter
- Recycling

Case Study – Material Selection

- **Problem: Select suitable material for bicycle frame and fork.**

Steel and alloys
Low cost but Heavy. Less Corrosion resistance

Wood
Light and strong. But Cannot be shaped

Carbon fiber Reinforced plastic
Very light and strong. No corrosion. Very expensive

Aluminum alloys
Light, moderately Strong. Corrosion Resistance. expensive

Ti and Mg alloys
Slightly better Than Al alloys. But much expensive

Cost important? Select steel
Properties important? Select CFRP